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This document is designed primarily to describe the U.S. Space Program, its history, its current state of development, and its goals for the future. Chapter headings include: Space and You; The Early History of Space Flight; The Solar System; Space Probes and Satellites; Scientific Satellites and Sounding Rockets; Application Satellites, Unmanned Lunar and Interplanetary Spacecraft; Manned Space Exploration; The Space Launch Vehicles, Biological Considerations in Space Explorations; Astronaut Selection and Training; Rocket Propulsion Principles and Techniques; Electric Power Generation, Guidance, and Communication; and Other Research Activities. The publication is liberally illustrated with photographs, diagrams and tables. (BR)

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Space: The New Frontier

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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An Educational-Informational Book / Space: The New Frontier

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THE AGE OF SPACE If there has been a single factor responsible for our success over the past two hundred years, it has been the characteristic American confidence in the future. It was such a confidence which brought the first colonists westward across the Atlantic to settle the Eastern shores. It was that same confidence which brought other generations westward across the continent to build up our country all the way to the Pacific. ☆ Today there are those who argue that we should not push forward into new realms or new enterprises except when there is clear evidence of competition from other nations. I believe the American people reject the concept that their future shall be measured by the reaction to accomplishments of others. ☆ America's commitment to the exploration of space for peaceful purposes is a firm commitment. We will not retreat from our national purpose. We will not be turned aside in our national effort by those who would attempt to divert us. ☆ Our national purpose in space is peace—not just prestige. PRESIDENT LYNDON B. JOHNSON

THE U.S. SPACE PROGRAM The U.S. Space Program was undertaken in 1958, and accelerated because three Presidents and the Congress considered it basic to our national strength and essential to our continued leadership of the free world. ☆ Among the major motivations of the space program is the necessity that we retain unquestioned preeminence in all areas of science and technology, including the new arena of space. Others include the demands of national security, the potential economic benefits of space technology, the anticipated new scientific knowledge which exploration of space would yield, and finally, the stimulating effects of this challenging national enterprise on all segments of American society, particularly the young. ☆ During the intervening years, the United States has made great progress in building the basic structure for preeminence in space. This is the structure which will, within this decade, enable man to explore the moon. Even more important, however, it is the structure which will give the Nation the capability to operate in and use space for whatever purpose the national interest may require—whether it be operations in near-earth orbit, or the search for extraterrestrial life on the planets beyond. ☆ Among the important benefits of the hard-driving space program now underway are: Development of high-thrust boosters with payload capabilities exceeding any others now known to exist. ☆ Development of superior guidance and control, the perfection of rendezvous and docking techniques—the ability to join two space craft in orbit at 18,000 miles an hour—and the ability to maneuver accurately in the space environment. ☆ Establishment of a structure of massive ground facilities to assemble, test, and launch space vehicles which will serve the Nation's needs for many years to come. ☆ Development of a strong industrial base which will be able to undertake the development and manufacture of any space systems required in future years. ☆ The development of great scientific competence in the Nation's universities and research laboratories on a broad basis throughout the Nation. ☆ Training of scientists and engineers through the conduct of basic research in the universities, and support of predoctoral training grants. ☆ Establishment of a reservoir of technicians in industry, training of astronauts and of military personnel for future needs in space. ☆ For the first time in the history of mankind the opportunity to leave the earth and explore the solar system is at hand. Only two nations, the United States and the Soviet Union, today have the resources with which to exploit this opportunity. Were we, as the symbol of democratic government, to surrender this opportunity to the leading advocate of the Communist ideology, we could no longer stand large in our own image, or in the image that other nations have of us and of the free society we represent. JAMES E. WEBB, *NASA Administrator*

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Space and You

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Man has taken long steps across the frontiers of the unknown since the opening of the Space Age in 1957. His unmanned spacecraft are blazing trails to the Moon, Mars, and Venus that he is preparing to follow. His satellites are broadening his knowledge about space near and distant from earth and about earth itself.

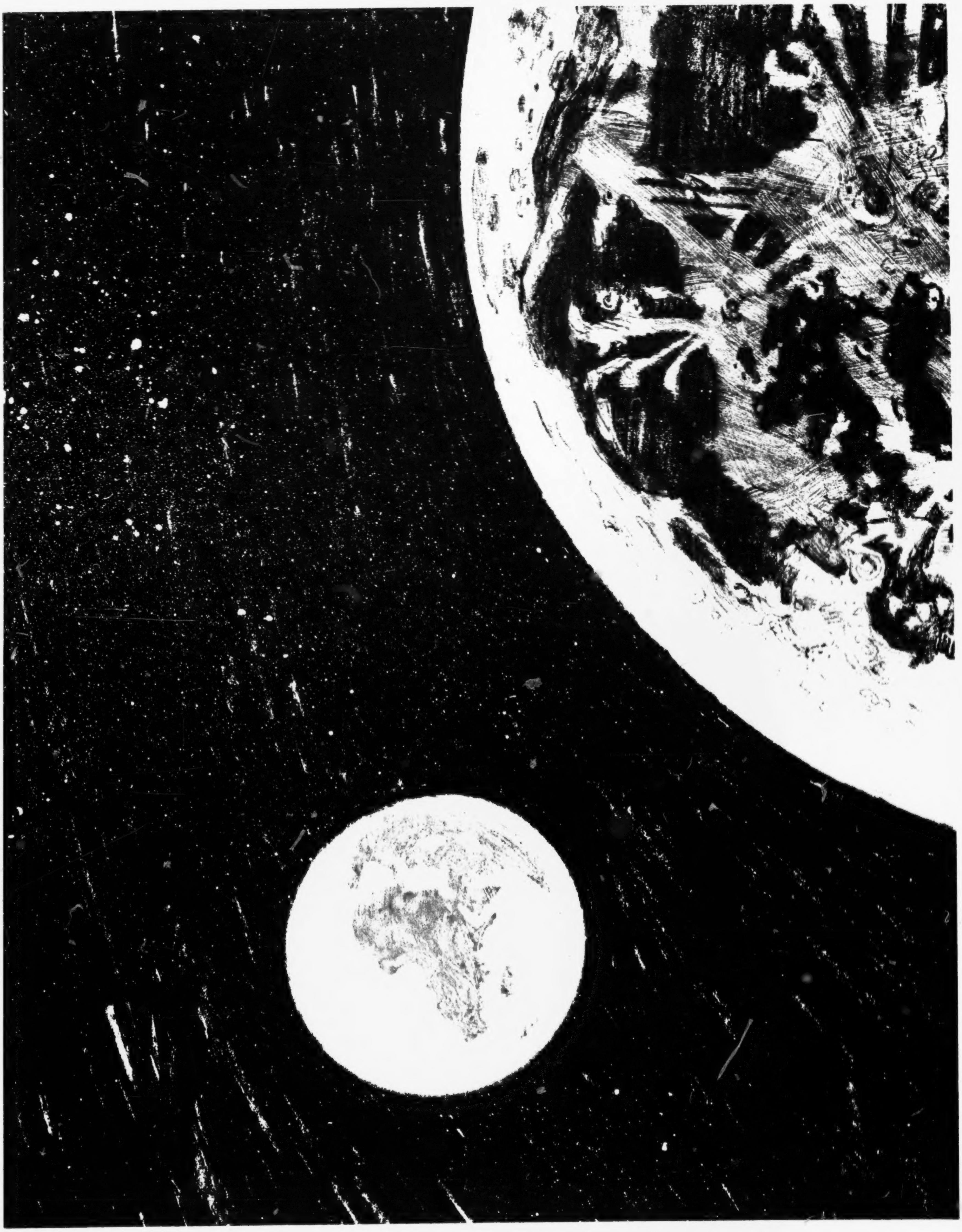
Man-made satellites are also expanding global communication channels, improving accuracy of weather forecasts, and showing promise for assisting in air and water navigation around earth. These are the more notable examples of the thousands of ways that new knowledge gained from the space program contributes to improvements and benefits in day-to-day living.

And just as the space program benefits man in many different ways, so the program itself is the product of many different organizations. It employs the knowledge, skills, and efforts of thousands of people in Government, industry, and the academic world here and abroad.

More than 90 percent of NASA's budget pays for work done by industry and the universities. Generally, NASA plans and directs space activities. American industry usually is responsible for developing the spacecraft, instruments, and other equipment to carry out these plans. Universities frequently conceive and design experiments for use on spacecraft. They conduct basic research in support of space programs and train students in scientific and engineering areas required for the programs.

STEP BY STEP INTO SPACE Among the nine planets which revolve about our sun, earth ranks only fifth in size. Pluto, a "neighbor" in our solar system, is more than 3½ billion miles distant and yet it, like the earth, is held in its orbit by the massive gravitational attraction of the sun, and the sun is 100 times as massive as the largest planet in its family of 9.

Yet, this sun itself is only a minor star. Its nearest neighboring star is so far away that even billions of miles are too puny a measure of distance. We must use instead the light-year, the distance traveled in 1 year at the speed of light. Light travels 186,300 miles per second, making 1 light-year about 6 trillion miles. Proxima Centauri, the star nearest our sun, is approximately 4⅓ light-years from earth. The farthest galaxy man can see in his biggest telescope is



about 10 billion light-years away.

Both Proxima Centauri and our sun are stellar members of the galaxy we call the Milky Way, a grouping of an estimated 200 billion stars so immense it would take 100,000 years at the speed of light to traverse its length. And, this galaxy is only one of several billion within the range of the world's largest telescope.

Viewed in man's terms of time and distance, the challenge of space exploration might seem insuperable. Yet one has only to review the technological accomplishments of mankind in the 20th century and the "impossible" becomes merely "difficult."

Space does not submit readily to conquest. The exploration of space is following the pattern by which man mastered flight within the atmosphere, each new development providing a platform from which to take the next step and each step an increment of scientific knowledge and technological skill.

The first goal, of course, is the exploration of our own solar system. This in itself is an assignment of awesome dimensions, but one which few in a position to evaluate doubt can be accomplished. There are no plans, at the present, for exploration beyond our solar system—only dreams. But, who would say these dreams will not some day be realized.

THE EXPLORATION OF SPACE AND YOU The exploration of space affects your life today; it will continue to affect your life more and more.

Man's activities in space affect your thinking, your reading, your conversation and many facets of your everyday life.

Space exploration is a consideration in national and world politics. Our government has spent billions on research, development, testing, and production in the space field. Thousands of scientists, engineers, and other technicians are engaged in space activities.

Space exploration has affected the trends of science. If you are a student at any level, space exploration affects your studies. It is rewriting your texts.

Whatever age you may be, it is probable that you come into almost daily contact with some product or byproduct which is the result of space research.

Drawing broadly from all fields of science and engineering, space technology offers promise of uncovering a flood of new benefits for mankind. NASA has established an Office of Technology Utilization to aid in identifying and disseminating useful information about those new processes, materials, equipment, and other innovations which can improve life on earth.

In accomplishing its mission, the office may significantly reduce the time gap between advances in knowledge and technology and their effective use throughout society.

SPACE AND WEATHER Satellites equipped with television cameras and infrared sensors make possible observations over areas not previously covered, and provide types of meteorological measurements not otherwise available. The reduction and analysis of these increased data, particularly from areas otherwise lacking observation, make possible better short-range forecasts, and may eventually improve long-range weather predictions.

Satellite observations provide warnings of tornadoes, floods, blizzards, hurricanes, and other catastrophic weather, enabling people to strengthen levees, take shelter, and make other preparations to minimize loss. Weather-sensitive industries such as shipping, airlines, agriculture, and construction gain enormously by improved weather

forecasts that satellites make possible. With long-range prediction of rainfall or drought, communities could better prepare for control of their watersheds. Increased meteorological knowledge attained by study of satellite data may eventually enable man to modify weather to his advantage.

NAVIGATION BY SATELLITE It is estimated there are 20,000 surface craft at all times on the Atlantic Ocean alone. Hundreds of aircraft crowd the skies over much of the world. Accurate information as to his exact location has become a necessity to the navigator of every sea or air craft.

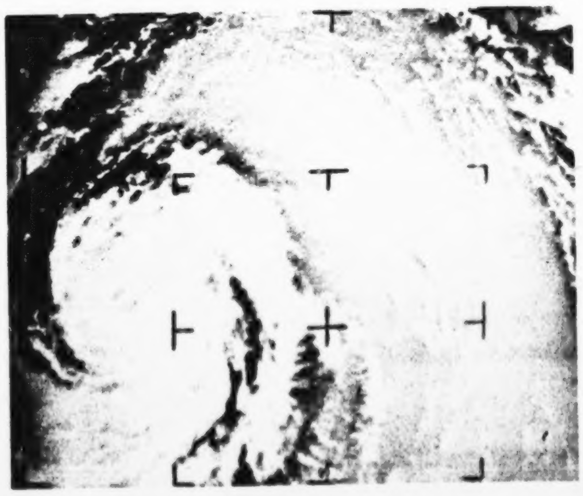
With navigation satellites, air and sea craft can receive information which will pinpoint their location any time of day or night and in all kinds of weather and enable them to steer along safe courses.

COMMUNICATIONS VIA SATELLITE Satellites have opened a new era in global communications. They not only can greatly augment current facilities but also make possible global telecasts and other types of world-wide communications not previously available. The world's first commercial communications satellite, Early Bird, was launched April 6, 1965. From a position high above the Atlantic Ocean, the satellite made possible trans-

1. *Hurricane photographed by Nimbus I weather satellite.*

2. *Astronaut Edward H. White II is photographed outside of his orbiting Gemini 4 spacecraft on June 3, 1965.*

3. *The rendezvous in orbit of the manned Gemini 6 and 7 spacecraft on December 15, 1965. The photograph was taken through the window of Gemini 6.*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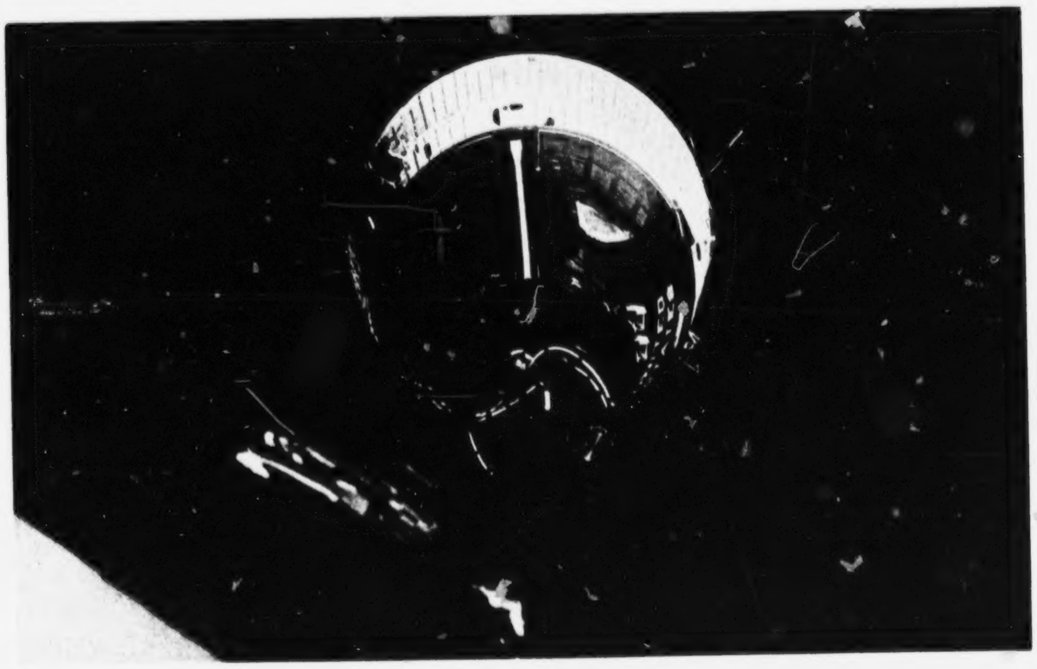
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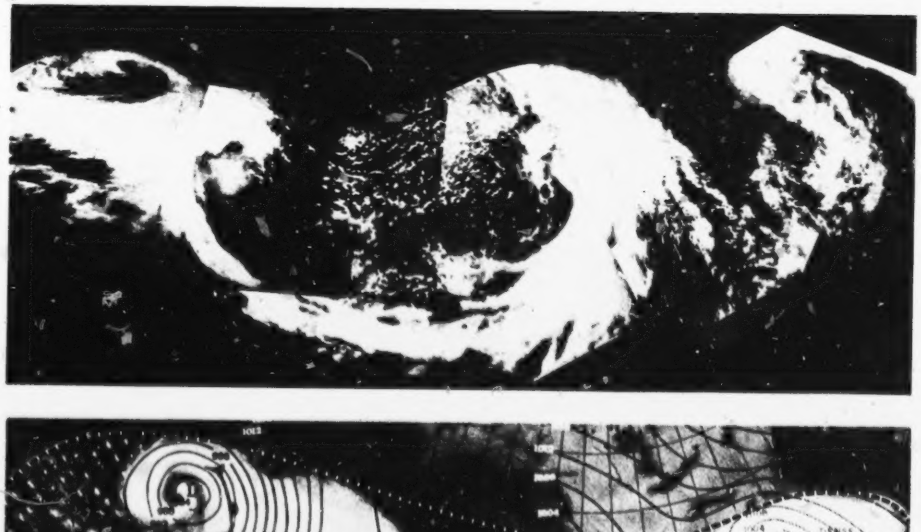
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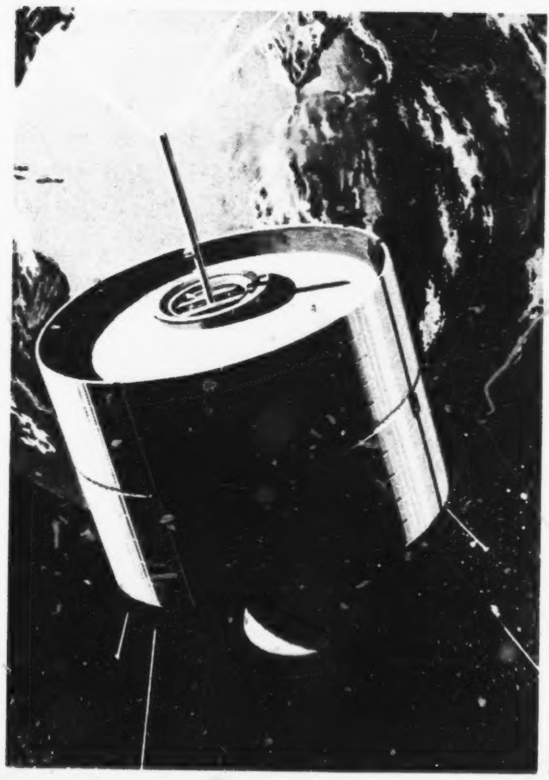

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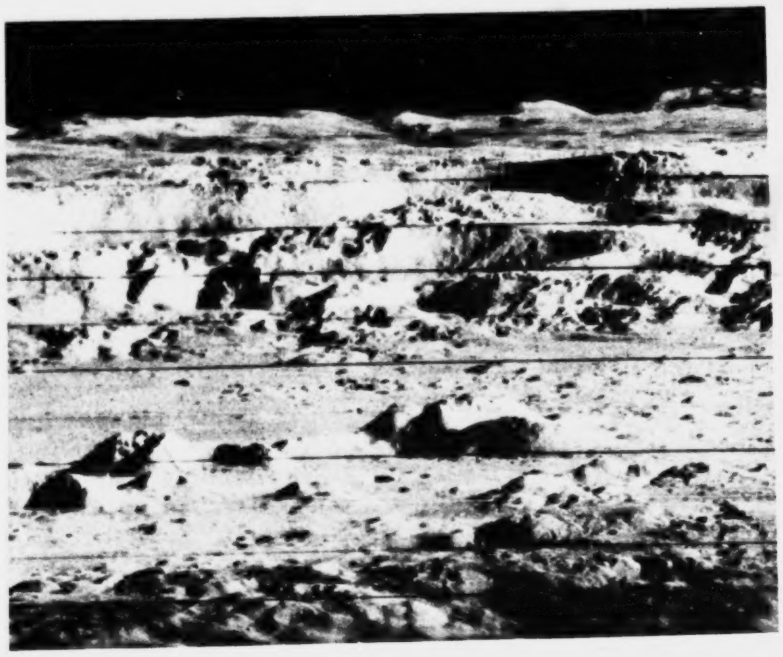
mission of television programs and other communications between Europe and the Western Hemisphere.

Several types of communications satellite systems have been and are under study. Among them are the aluminized plastic spheres, Echo I and Echo II, which have been seen by many people throughout the world. The huge balloon-like satellites, bearing no communications equipment, function by reflecting radio signals back to the ground. They are called "passive" satellites.

Another kind of communications satellite is called "active-repeater." This kind contains equipment to receive and transmit messages. They serve, in effect, as orbiting radio relay stations.

Tests have been made of active-repeater satellites in medium-altitude (up to 12,000 miles) and synchronous-altitude (22,235 miles) orbits. A synchronous satellite takes as long to make one revolution as the earth takes for a complete rotation on its axis. If the satellite's orbit is circular and is in the equatorial plane, the satellite will remain over one spot on the earth's surface. To an observer on earth, it would appear to be stationary. (The plane of a satellite's orbit may be visualized as a flat plate whose rim is the satellite's orbit. If



1. *Use of weather satellite cloud pictures. Information from mosaic of TIROS weather satellite cloud pictures is overlaid on map and reduced to operational weather data for incorporation in Weather Bureau analysis and forecasts.*

2. *Early Bird I communications satellite over the Atlantic (artists conception).*

3. *The moon's Crater Copernicus as photographed from an oblique angle by Lunar Orbiter II.*

the plate bisects earth at the equator, the satellite is orbiting in the earth's equatorial plane.)

Experiments with satellites in medium altitudes were carried out in NASA's Project Relay and the Telstar project of the American Telephone and Telegraph Co. NASA's Project Syncom demonstrated the feasibility of using active-repeater satellites in synchronous orbits for communication. Early Bird, first satellite of the Communications Satellite Corporation, is in a stationary synchronous orbit over the Atlantic Ocean. Chapter VI briefly describes the Echo, Relay, Telstar, Syncom, and Early Bird programs.

ASTRONOMY VIA SPACECRAFT Astronomers have been handicapped by the earth's atmosphere which screens out or distorts electromagnetic radiation. About 99 percent of the atmosphere's air molecules are concentrated between the earth's surface and an altitude of about 20 miles. By placing telescopes and other equipment for studying the heavens in observatories above this altitude, man can see the universe from a vantage point above the haze of the atmosphere.

Orbiting solar observatories have provided new information about the sun; about how variations in solar activity influence earth's atmosphere and magnetic fields; and about the amount of cosmic radiation that reaches earth's surface.

By means of future orbiting observatories, man will be able to acquire more definite information about the nature and origin of the solar system. He will be able to view in greater detail the physical features of earth's moon, of Mars, and of other planets.

With earth-based telescopes, man has gathered data about his own Milky Way galaxy and other galaxies. He has found evidence of planets revolving around other stars. Mounted on a platform in space, man's telescopes can reveal hitherto unavailable information about stars and galaxies. Perhaps, they may enable him to learn about the existence of planets that resemble earth. They may rewrite texts on astronomy from the solar system to extra-galactic phenomena.

A glimpse of advances in knowledge to be gained by space exploration was given in the successful Mariner flights past Mars and Venus and the Ranger, Surveyor, and Lunar Orbiter flights to the moon. The spacecraft returned information never before available to man. Chapter III, The Solar System, describes some of their findings.

GEODESY AND SPACE Satellites assist in determining exact distances and locations and precise shapes of land and sea areas on earth. They also increase accuracy of measurements of the shape and size of the earth and of variations in terrestrial gravity. Such information advances the preparation of accurate global maps and augments scientific knowledge about our planet.

PHYSICS AND SPACE With satellites, the physicist has a new tool for study of the earth, the earth's atmosphere, and the earth's magnetic field. With interplanetary spacecraft, the physicist can study the solar wind, the stream of hot electrified atomic particles (protons and electrons) coming from the sun. He can study cosmic and other forms of radiation in space and interplanetary magnetic fields. When landings are made on earth's moon and on other planets of the solar system, the physicist may gain a new perspective of his area of science. Generally, space offers the physicist a vast laboratory by which he can greatly extend his studies made on earth. In such a laboratory, he will not only greatly increase his knowledge of the space environment but also of the earth itself.

ADVANCES IN TECHNOLOGY Apart from immediate benefits derived from expanded knowledge and direct applications of satellites, there are tremendous technological gains that accrue as a result of the research and development performed by NASA and its contractors. Such gains gradually are reflected in products, materials, techniques, and processes that benefit all mankind.

For example, the space program demands systems that operate without repair or maintenance for prolonged periods. To do this, manufacturers must improve techniques of production, upgrade quality control, develop new designs, and create new materials.

A "magnetic hammer" developed to smooth out distortions in the walls of large rocket booster sections is being considered for other uses, including shipbuilding. The force that does the hammering is a magnetic field set up by a strong but micro-second short electrical pulse. Because the magnetic field pressure is distributed throughout the material being hammered, its resultant metal forming is uniform without surface blemishes.

Development for NASA spacecraft of small lightweight computers has made available for industry more compact and economical computers. More generally, progress in computer technology is being accelerated through the combination of engineering improvements and the need to adapt them for space purposes.

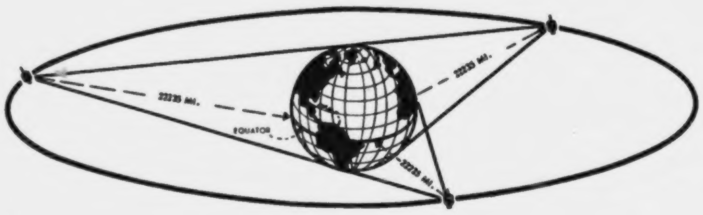
The program to improve the solar cells which power most United States satellites and interplanetary probes points to the day when the cells will be commercially economical. The cell converts sunlight to electricity.

Research on pigments and other coating materials aimed at reflecting the sun's heat from the fuel tanks of spacecraft has industrial applications in such fields as refrigeration, fuel storage—may even point the way to improve home insulation.

An equally significant by-product of the space program is the development of management systems that can effectively mobilize vast quantities of materials, hundreds of thousands of workers and organizations. and coordinate men. organizations, and materials to achieve goals of rapid high-quality research, technological development, and production.

MEDICINE The study of aerospace medicine promises benefits in the treatment of heart and blood ailments. Significant studies have been made on human behavior and performance under conditions of great stress, emotion and fatigue. Discoveries have been made as to what type of man can best endure long periods of isolation and removal from his ordinary environment. A derivative of hydrazine (isoniazid), developed as a liquid space propellant, has been found to be useful in treating tuberculosis and certain mental illnesses. And the space industry is producing such reliable and accurate miniature parts—such as valves—that they may some day be used to replace worn-out human organs.

In April 1963, an electroencephalogram depicting brainwaves from an American woman was sent across the Atlantic from England to the United States and a diagnosis returned via NASA's Relay communications satellite. The experiment, in which the brainwaves of a healthy individual were trans-



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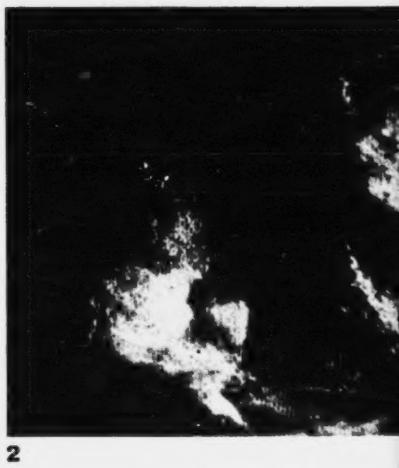

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mitted, was designed to test the possibility of swift diagnosis of brain disorders by specialists in different parts of the world through use of communications satellites. It points the way toward accelerated processing of medical data by use of communications satellites.

The idea of a remotely operated instrument carrier for unmanned exploration of the moon has been adapted to build a wheel chair that literally walks. It can move across sandy and rough terrain and negotiate curbs and steps. It can be operated without the use of arms and hands.

A switch has been developed to enable an astronaut to operate his spacecraft controls by voluntary eye movements when his arms and legs are immobilized due to the high gravity forces of either acceleration or deceleration. Such a switch lends itself to many medical and nonmedical uses. For example, with such a switch a paraplegic can operate a motorized wheelchair or an electric typewriter. Bed patients can control room lights, thermostats, radios, television sets, and other electrically operated equipment and appliances.

Scientists and dietitians are working directly on the problem of space feeding and nutrition. The information gained from this research can have a profound influence on future food and agricultural processes. This involves the growth of synthetic and new foods, and the process of compressing large numbers of calories into pill-size packages. It involves also new methods of food growth and storage.

NEEDED: SPACE SCHOLARS No enterprise in history has so stirred the human imagination as the reaching of man into space.

New knowledge to cope with this challenge is needed in almost every brand of technology. This need encompasses the basic sciences of physics, chemistry, engineering, and mathematics. It also includes biology, psychology, and almost every field of medicine.

Many college and university courses deal with astronautics. High schools have space science courses or incorporate space concepts into physics and other science courses. Elementary curricula include space studies in their science program.

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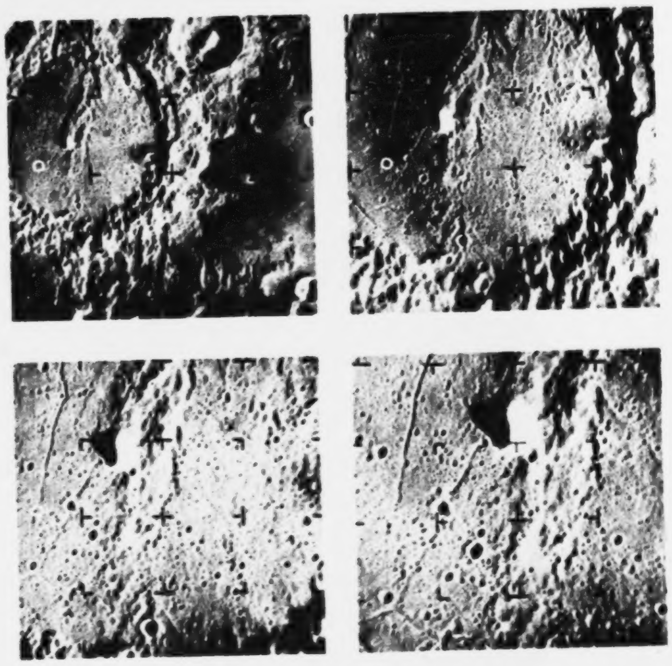

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1. Three synchronous satellites, spaced equidistant around the globe, could provide nearly world-wide communications coverage. As many as fifty lower-altitude satellites would be required to match this coverage.

2. The Great Lakes of the United States and Canada as seen by TIROS weather satellite camera.

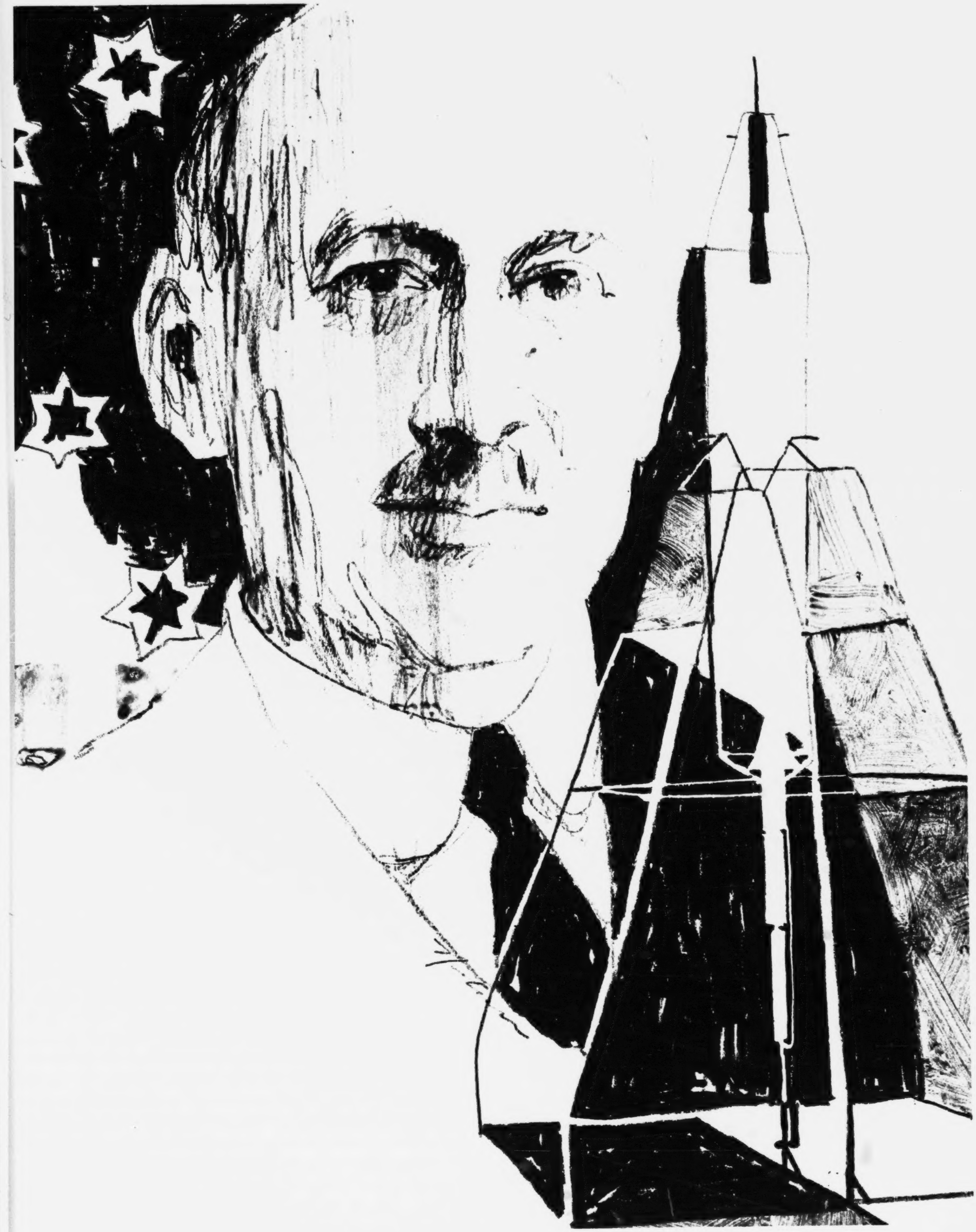
3. Technicians check fittings of space suit of Astronaut Frank Borman, command pilot of Gemini 7 spacecraft. Note attachments to scalp for acquiring medical data.

4. Ranger IX close-ups of the moon's Crater Alphonsus taken as the spacecraft plunged toward impact point indicated by small white circle.

The Early History of Space Flight

II

The beginnings of thought about space flght were a mixture of imagination and vague concepts. The idea of leaving the earth to travel to a distant world developed only as understanding of the universe and the solar system evolved. ¶ In 160 B.C. a part of "Cicero's Republic," entitled "Somnium Scipionis" (Scipio's Dream), presented a conception of the whole universe, a realization of the comparative insignificance of earth and the visualization of a vast panorama in which appear "stars which we never see from earth." Lucian of Greece wrote his Vera History in A.D. 160, the story of a flight to the moon. For centuries no further stories of space travel appeared. Only with the renaissance of science and the work of such men as Tycho Brahe, Copernicus, Kepler, Newton, and Galileo did men's minds again become receptive to the possibility of traveling to other worlds. ¶ In rapid succession, such writers as Voltaire, Dumas, Jules Verne, Edgar Allan Poe, H. G. Wells, and many other lesser known authors filled the pages of literature with imaginative tales of space travel. ¶ A fascinating novel is "The Brick Moon" by Edward Everett Hale, who is better known for his "The Man Without a Country." First published in 1869, "The Brick Moon" is the first known presentation on the injection of a manmade satellite into orbit. The novel was the first to discuss the manned orbital laboratory and weather, communications, and navigation satellites. ¶ Today one has only to go to the closest magazine stand or bookstore to find similar stories. Dramatizations have appeared on the motion picture screen, radio, television, and the legitimate stage. ¶ The history of rocket development is interwoven with evolving ideas of the universe and space travel, because only with the rocket principle is travel in space possible. Yet, the rocket is an ancient device. ¶ When the first rocket was fashioned remains a secret of the past, but there is no doubt that the earliest known direct ancestor of our present day rockets was a Chinese invention. In A.D. 1232, at Kai-fung-fu the Chinese repelled attacking Mongols with the aid of "arrows of flying fire." This was the first recorded use of rockets. These early rockets reached Europe



by 1258. They are mentioned in several 13th- and 14th-century chronicles. In 1379, a lucky hit by a crude powder rocket destroyed a defending tower in the battle for the Isle of Chiozza. This was during the third and last Venetian-Genovese war of the 14th century. The Genovese fleet sailed up the Adriatic, laid siege to and took Chiozza, although later losing the war when the Venetians bottled up the fleet in the Chiozza estuary.

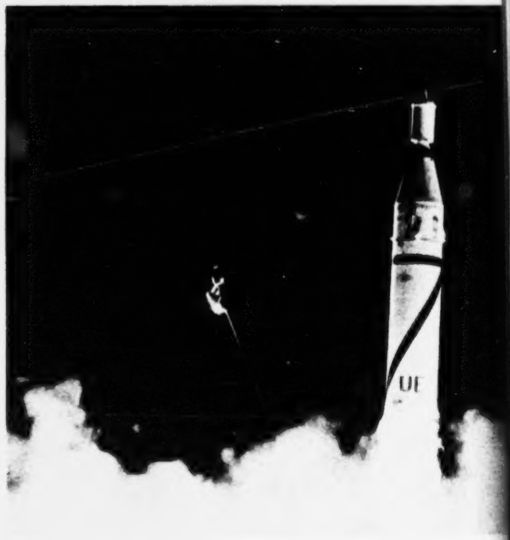
The early 19th century brought a period of intense interest in the military rocket. Great Britain's Sir William Congreve developed a solid-propellant rocket which was used extensively in the Napoleonic Wars and the War of 1812. One of the more spectacular of the Congreve rocket achievements was the razing of the greater part of Copenhagen in 1807. The "rocket's red glare" in the "Star Spangled Banner" was created by Congreve's rockets fired by the British during their siege in 1814 of Fort McHenry near Baltimore.

As so often happens with articles designed for war use, the Congreve rocket was adapted to humanitarian purposes. The most useful outgrowth was a lifesaving rocket first patented in Britain in 1838. This device (using a Congreve rocket) carried a line from shore to a stranded vessel, enabling the distressed crewmen to be pulled back to shore on a breeches buoy. Almost a century passed before rocketry advanced further. In 1903 a Russian schoolteacher, Constantin Tsiolkovsky, published the first treatise on space travel advocating the use of liquid fuel rockets. This paper remained unknown outside Russia, and at that time little attention was given it by the Russians.

While the theories of Tsiolkovsky remained in obscurity, Robert H. Goddard, an American, and Hermann Oberth, a Rumanian-German, working separately, laid the foundation for modern rocketry. Professor Oberth provided the chief impetus for experimental rocket work in Germany when, in 1923, he published his book, "The Rocket Into Interplanetary Space." Professor Oberth discussed many problems still faced by rocket scientists and explained the theories and mathematics involved in lifting an object from earth and sending it to another world. The inspiration for the formation of the German Society for Space Travel (Verein fur Raumschiffahrt) came from Hermann Oberth's book. Both Oberth and Goddard favored the liquid-fuel rocket.

Dr. Goddard, a professor at Clark University in Massachusetts, sent a finished copy of a 69-page manuscript to the Smithsonian Institution in 1919 as a report on the investigations and calculations that had occupied him for several years. This paper entitled, "A Method of Reaching Extreme Altitudes," caught the attention of the press because of a small paragraph on the possibility of shooting a rocket to the moon and exploding a load of powder on its surface.

Almost simultaneously with the publication of this paper, Dr. Goddard concluded that a liquid-fuel rocket would overcome some of the difficulties he had encountered with pellets of powder. For the next 6 years, Dr. Goddard worked to perfect his ideas. By 1926 he was ready for an actual test flight, and on March 16 launched the world's first liquid-fuel rocket. The flight to an altitude of 184 feet proved that this type of rocket would perform as predicted.



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Dr. Goddard launched the first instrumented rocket on July 17, 1929, with a barometer, a thermometer, and a small camera focused to record the instrument readings at maximum altitude.

Public reaction to the increasing noise and size of Dr. Goddard's rockets forced him to leave Clark University for the southwestern United States where he could continue his work in more open spaces without endangering his neighbors. Through continual improvement, his rockets by 1935 reached 7,500 feet and speeds of over 700 mph. By the late 1930's Dr. Goddard was recognized, at least in professional circles, as probably the world's foremost rocket scientist. His early work and patents were known to the German Society for Space Travel. Members of this Society devel-

1. *Explorer I is launched.*
2. *Dr. Robert H. Goddard stands beside the liquid fuel rocket he launched on March 16, 1926. This launching, the first ever accomplished for liquid fuel rockets, was made from Auburn, Massachusetts.*
3. *Dr. Goddard stands beside another one of his rockets. Place: Roswell, N. Mexico. Time: 1935.*
4. *American Rocket Society members test liquid fuel rocket in 1935.*
5. *Launch of V-2 with WAC-Corporal second stage.*

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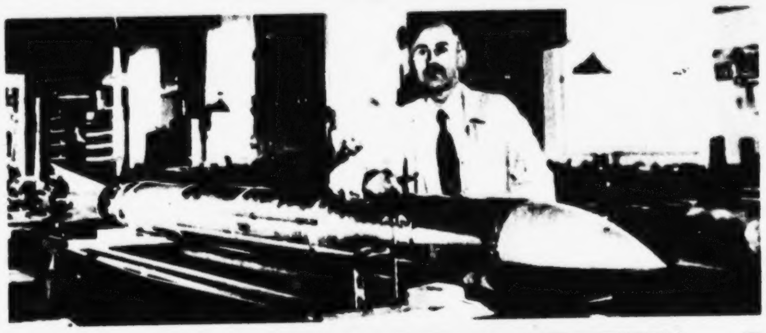

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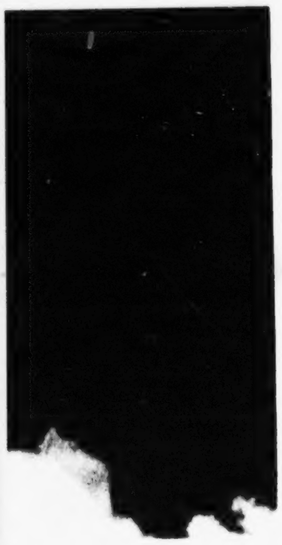

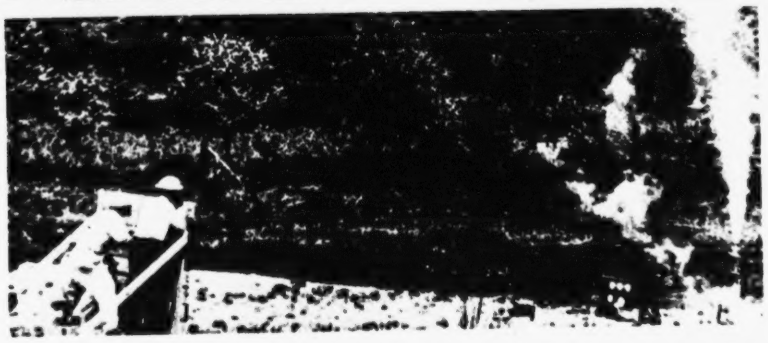

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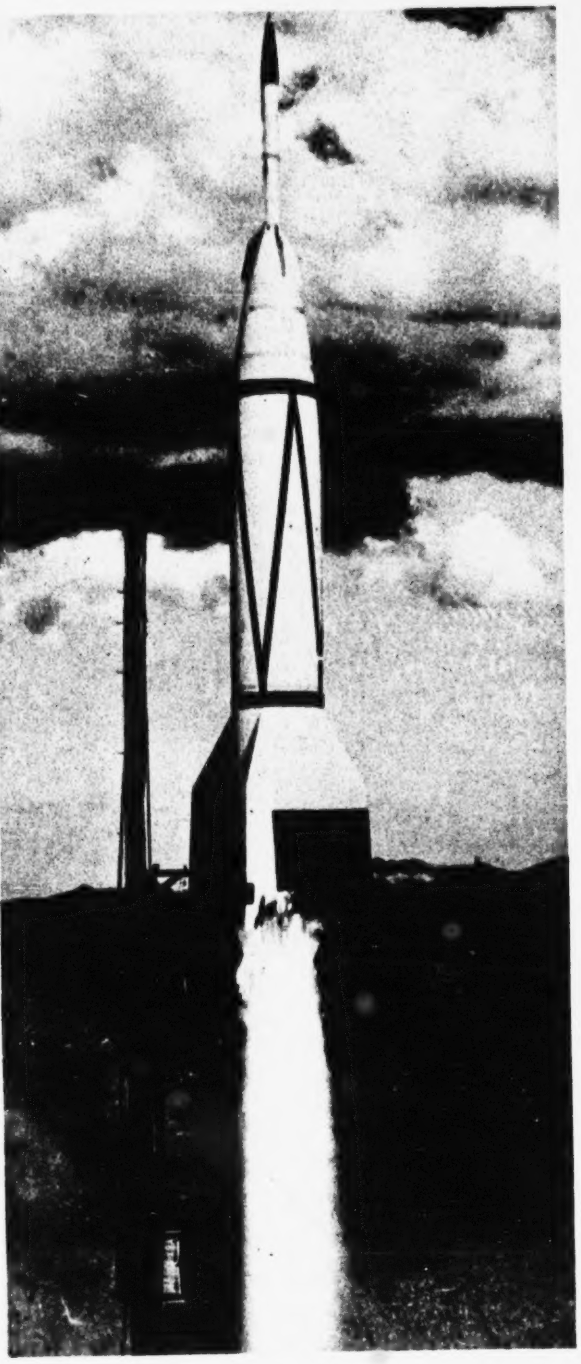

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oped the V-2 missile used during World War II. American rocket enthusiasts formed the American Interplanetary Society in 1930, later changing their name to the American Rocket Society. The test firings and meetings of this group stimulated a growing awareness of rocketry and its capabilities in the American public. Many members now are responsible for current space programs.

After World War II, the United States experimented with captured German V-2 rockets to advance its knowledge of liquid rocket technology. On February 29, 1949, United States experimenters at White Sands, New Mexico, launched a V-2 with an American-developed WAC-Corporal second stage to a record 244-mile altitude. The Aerobee and Viking sounding rockets were also developed for high altitude scientific experiments.

The post-war development of missiles produced several types that could be adapted to space missions. Among these were Jupiter, Thor, Atlas, and Redstone. By 1955, the United States and the Soviet Union had initiated programs to launch satellites for the International Geophysical Year (IGY) to take place from July 1957 through December 1958. In the IGY, the world's scientists cooperated to learn more about the earth and sun and solar-terrestrial relationships.

On October 4, 1957, the Soviet Union launched the world's first artificial satellite, Sputnik I, into orbit. On January 31, 1958, the United States launched its first satellite, Explorer I.

The world had entered the Age of Space.

The Solar System

III

The solar system man hopes to explore is tiny in relation to the universe as a whole, but it is an area of tremendous magnitude in earth terms. Its primary, our sun, is a star located at the center of the system with nine planets revolving around it in near-circular orbits. Some of the planets, like earth, have natural satellites of their own (Jupiter has 12), and there are thousands of other bodies moving within the system. ¶ The planets are held in their orbits by the sun's gravity. They all move in the same direction around the sun and their orbits lie in nearly the same plane, with Pluto the exception. Their orbital speeds are higher near the sun. Mercury, the planet nearest the sun, makes a circuit in 88 days. Earth's period of revolution is 365¼ days. Distant Pluto, more than 3½ billion miles from the sun, takes 248 earth-years to make one circuit.

THE SUN The sun represents more than 99 percent of the total mass of the solar system. Its mass is 330,000 times that of earth's and its volume more than a million times greater. ¶ Every 11 years, the number of dark spots on the solar surface, called sunspots, reaches a maximum. These spots show strong magnetic fields. During the maximum of a sunspot period, the sun shows marked activity in shorter "wavelengths"—X-rays and ultraviolet radiation. Frequent solar eruptions and solar flares occur. These produce definite effects on earth, such as ionospheric disturbances, magnetic storms, interruptions of radio communications, unusual auroral displays, and a lowering of the average cosmic ray intensity. Giant solar flares are a hazard to manned space exploration in that they may subject man, if he is unprotected, to lethal doses of radiation. A reliable system of forecasting major solar flares is crucial to the safety of men in space. ¶ Besides sunspots and solar flares, scientists are studying, by means of satellites, interplanetary probes, sounding rockets, balloons, and ground-based observatories, numerous other solar features. These include the solar wind—a constant outrushing of hot electrified gas (chiefly protons of hydrogen atoms) from the sun's turbulent surface; the photosphere which

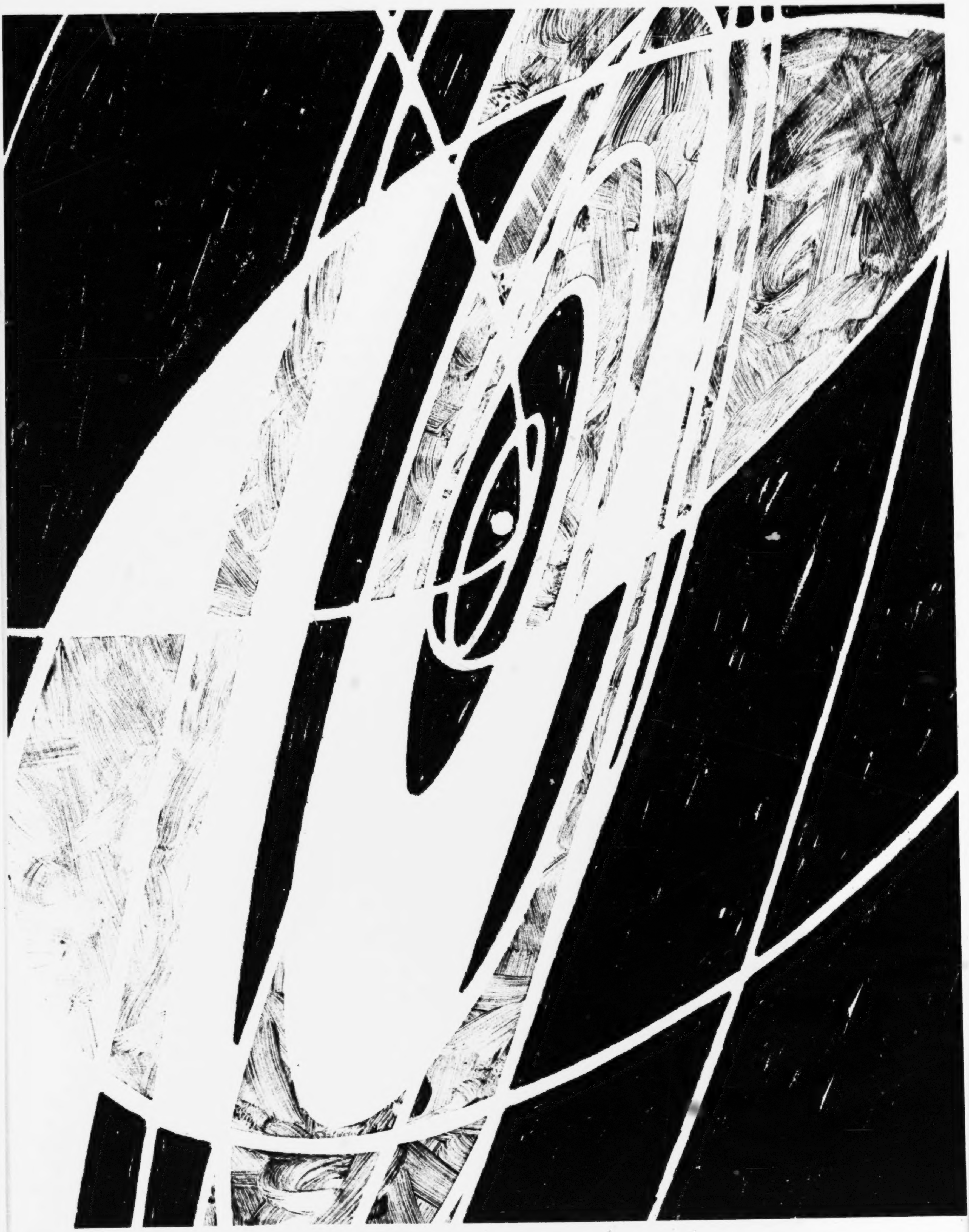


TABLE I. SOME PLANETARY DATA

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Sidereal period—days/years	88 d	225 d	365.3 d	687 d	11.9 y	29.5 y	84.0 y	164.8 y	248.4 y
Mean distance from Sun									
millions of miles	36.0	67.2	92.9	141.5	483.3	886.1	1782	2792	3646
astronomical units‡	0.39	0.72	1.00	1.52	5.20	9.54	19.18	30.06	39.24
Orbital velocity—miles/sec.	29.8	21.8	18.5	15.0	8.1	6.0	4.2	3.4	2.9
Mean diameter—miles	3100	7600	*(e) 7927 (p) 7900	4200	(e) 88,700 (p) 82,800	(e) 75,100 (p) 67,200	29,300	27,700	5000?
Diameter—Earth = 1	0.39	0.97	(e) 1.00	0.53	(e) 11.2	(e) 9.5	3.7	3.5	0.6
Surface gravity—Earth = 1	0.36	0.87	1.00	0.38	2.65	1.14	1.07	1.41	?
Escape velocity—miles/sec.	2.6	6.4	6.9	3.1	37	22	14	15	?
Length of day	180 d	?	23 h. 56 m.	24 h. 37 m.	9 h. 50 m.	10 h. 14 m.	10 h. 49 m.	14 h. ?	6.4 d ?
Natural satellites			1	2	12	9	5	2	
Atmospheric composition (*i.e.,* so far discovered)	hydrogen? (very tenuous)	carbon dioxide water vapor	oxygen, nitrogen carbon dioxide, water vapor, etc.	carbon dioxide, water vapor	methane ammonia	methane ammonia	methane ammonia	methane ammonia	?
Surface temperature									
Maximum local noon	+660° F.	+800° F.	+140° F.	+50° F.	—216° F.	—243° F.	—300° F.?	—330° F.?	—350° F.?
Minimum midnight	—460° F.?	?	—120° F.	—90° F.	—	—	—	—	—

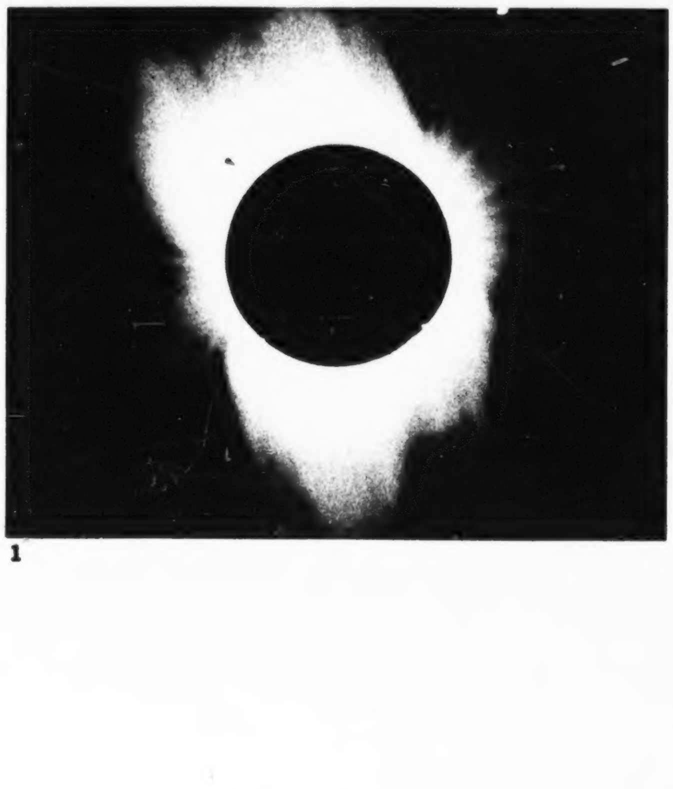
* (e) equatorial. (p) polar. d-days. h-hours. m-minutes. y-years.

† A complete rotation every 59 days. Rotation is direct; *i.e.,* it is in the same direction as the planet's flight around the sun.

‡ Astronomical Unit (AU). One AU is equivalent to earth's distance from sun.

is the visible disk of the sun on which sunspots occur and from which solar flares leap forth; plages, bright areas on the photosphere; prominences, streams of luminous condensed gas that rise above the sun's surface; the corona, or solar atmosphere, which is visible during eclipses or with special apparatus; and the chromosphere, a transition layer of gas between the relatively cool photosphere and extremely hot corona. The photosphere has a temperature of about 11,000 degrees Fahrenheit; the corona, about 3 million degrees Fahrenheit.

The temperature at the sun's center is calculated at about 25 million degrees Fahrenheit. It is in this vicinity where thermonuclear reactions convert hydrogen to helium and to energy which is emitted as radiation. Such radiation includes visible light and heat.



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Study of the sun is important because the sun provides earth with light and heat and controls the motion of earth and other solar system bodies. It is the only star whose surface is visible to man. All other stars appear as points of light, even in man's best telescopes.

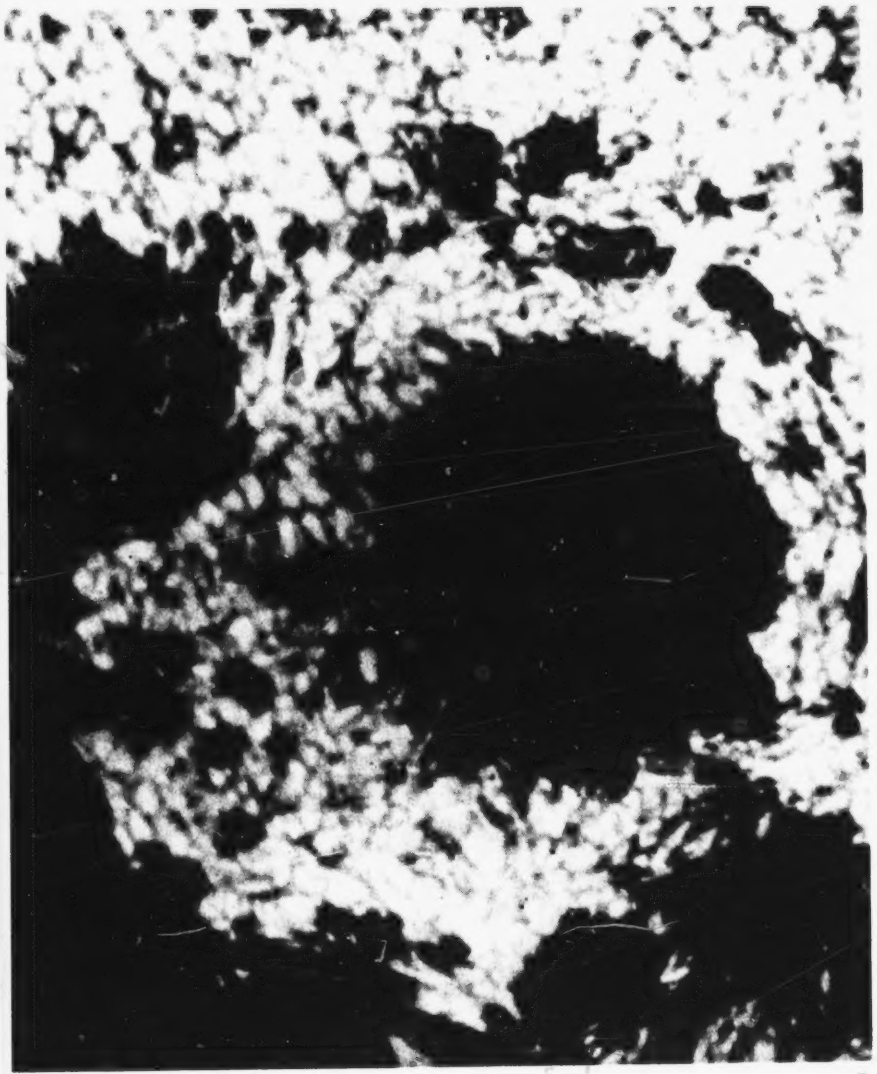
THE EARTH Life on earth is sustained by the light and the heat of the sun. Earth's atmospheric conditions are affected by solar energy.

Atmospheric pressure at the surface of the earth amounts to about 1 ton per square foot. This pressure decreases as the altitude increases. Thus, 99 percent of the atmosphere lies below 20 miles and all but one-millionth lies below 60 miles.

Although there is no exact or recognized boundary, this fact has led many space scientists and space writers to place the beginning of space—as far as earth is concerned—at 60 miles above the earth's surface.

Satellites have given man a new look at his planet. Man knows that his earth is surrounded by a zone or fence of intense radiation called the Van Allen Radiation Region. He knows that the radiation consists of speeding atomic particles (electrons and protons) trapped in earth's magnetic field.

For years, man visualized the magnetic field as looking like the assemblage of iron filings around a bar magnet. Satellites have shown that the magnetic field is shaped more like a tear drop. The magnetic field is pushed into this form by the solar wind—hot electrified gases rushing con-



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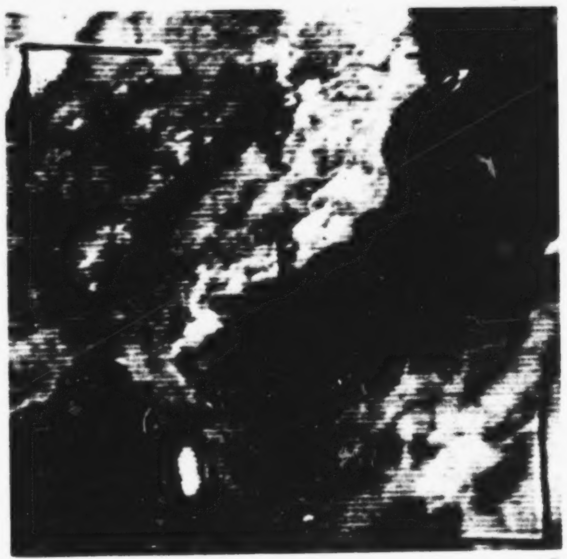

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stantly from the sun's turbulent surface.

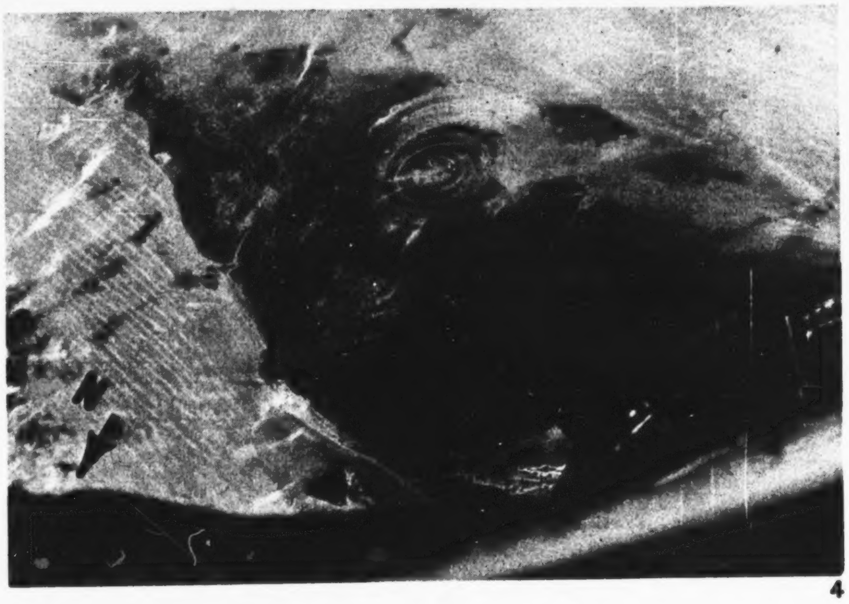
When the solar wind collides with earth's magnetic field, it creates another phenomenon—a shock wave. The wave is comparable to that created by an airplane traveling at supersonic speed (speed in excess of that of sound. Sound travels about 1100 feet per second at earth's surface.)

Scientists know from satellites that earth's upper atmosphere swells and contracts with increases and decreases in solar activity.

Satellite information has even changed man's picture of earth's contours. Earth had been presumed to be a sphere slightly flattened at the poles. Satellites told man that the earth tends to be pear-shaped and bumpy.

THE MOON The moon is the earth's only natural satellite. It revolves about earth from west to east every 27 days, 7 hours, and 43 minutes. The moon's distance from earth varies from 221,463 miles when the moon is at perigee (nearest to the earth) to 252,710 miles when the moon is at apogee (farthest from the earth). The mean distance is 238,857 miles.

The moon's orbital speed averages 2,287 miles per hour. Because it rotates in nearly the same length



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1. *Eclipse of the sun. The sun's corona, or atmosphere, becomes visible as a bright area surrounding the darkened sun.*
2. *Close-up of the sun's stormy surface. Dark areas are sunspots.*
3. *View of Strait of Gibraltar and parts of Spain, Africa, Mediterranean Sea, and Atlantic Ocean taken by camera of TIROS weather satellite.*
4. *Mysterious Richat structures in Northern Africa as photographed from Gemini spacecraft. Origin of the circular ridges is uncertain.*

of time as it takes to revolve about the earth, the moon presents the same side toward earth at all times.

The moon is 2,160 miles in diameter. The area of the moon is about one-fourth the surface of the earth and its circumference is about 6,800 miles. It appears to have no atmosphere.

NASA's Ranger spacecraft significantly advanced knowledge of the moon by returning to earth lunar pictures providing as much as 2000 times the detail seen from ground-based observatories. Ranger pictures showed that the seemingly smooth lunar seas, or plains, are pitted by thousands of craters not visible from earth.

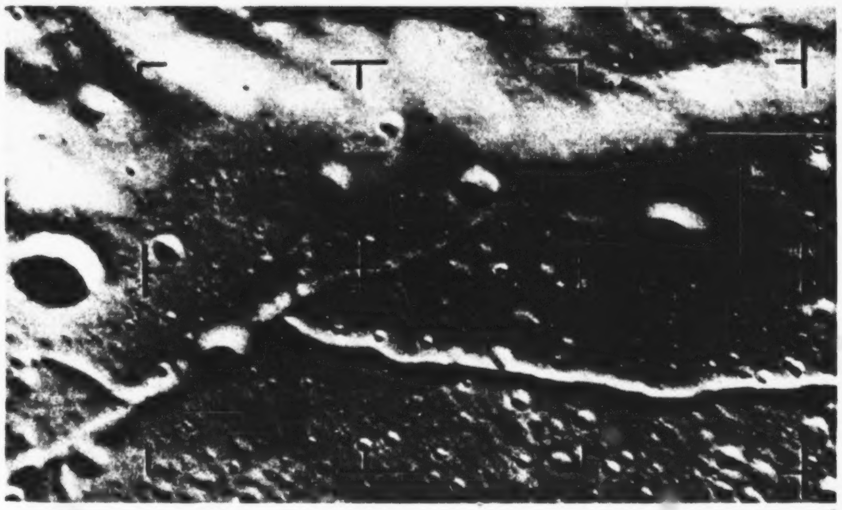
They also provided evidence that despite the absence of wind and water, erosion is a significant force on the moon. The peaks and slopes of many mountains and of numerous craters were seen to be rounded rather than rough and jagged. Fissures in the surface seemed to be filled in. Scientists are uncertain about the cause of such erosion. One suggestion is that it results from incessant bombardment by meteoroids, particles of matter in space.

Scientific investigators consider the close-ups of the crater Alphonsus taken by Ranger IX as providing strong evidence of volcanic activity on the moon. Certain so-called "halo" craters, visible from earth, are surrounded by dark areas. Ranger IX revealed other "halo" craters. Its close-ups showed that the "halos" were deposits of dark material on the moon's surface. It is believed that the deposits erupted through the "halo" craters. *Scientists in recent years have detected through observatories on earth what appeared to be gaseous emissions in the Crater Alphonsus and other lunar areas. Until these sightings, astronomers generally considered that the moon was a cold dead body with no volcanic activity.*

The Ranger close-ups of the moon have been made available to the world scientific community. It is anticipated that they will be studied for many years.

America's Surveyor I spacecraft landed gently in the moon's Ocean of Storms on June 2, 1966. The pictures that it telecast to earth tell us that it stands on a relatively level plain littered with small rock-like masses and pocked with small craters. Even more significant, Surveyor's successful landing indicated that spacecraft can touch down and men can walk safely on the moon.

MARS—MORE LIKE THE MOON THAN THE EARTH For years, scientists have considered Mars the most likely of other planets to harbor life.



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They have been supported in their belief by earth-based observations and studies that gave evidence of some moisture and atmosphere, and of color changes comparable to those accompanying growth of vegetation in springtime on earth.

A crater-scarred surface was among the Martian features first revealed to man in close-up photographs taken by NASA's Mariner IV spacecraft. The pictures, which are the first ever taken in the vicinity of another planet, were snapped on July 14, 1965, as Mariner sped by Mars at distances ranging from about 10,500 to 7400 miles.

The craters on Mars resemble impact craters on the moon; that is, they may have been caused by collision of large meteoroids with Mars. Scientific estimates of when the collisions occurred range from several hundred thousand to several billion years.

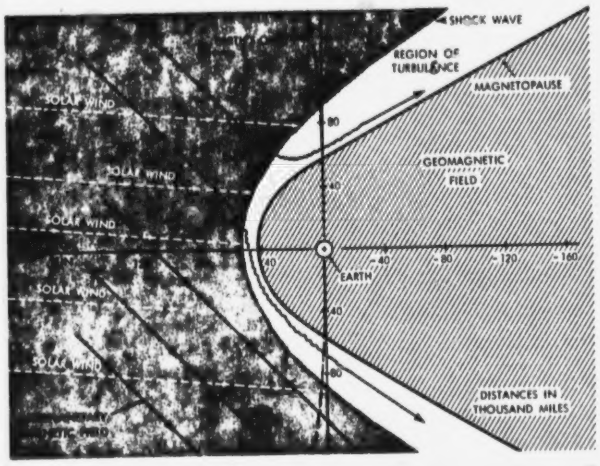
If the photographed area, *about one percent of the Martian surface*, is representative of the entire surface, Mars may be pitted by more than 10,000 craters of the sizes observed and many smaller craters. Approximately 70 craters, ranging from 3 to 75 miles in diameter, can be discerned in the photographs.

The photographs showed no physical features that could have been the basins of former oceans or the beds of ancient rivers, lakes, or seas. Several photographs cover areas crossed by the controversial Martian "canals." They reveal no readily apparent straight-line features that can be interpreted as artificial.

Mariner measurements show that man will require a pressure suit or have to remain in a pressurized cabin to survive on Mars. Mariner IV data indicated that the Martian atmosphere's surface pressure is lower than ten millibars, as compared to the approximately one thousand millibars of actual sea level pressure on earth.

Data from Mariner IV also indicated that Mars has an ionosphere, an electrically charged layer of the atmosphere that can reflect certain radio frequencies. This means that under certain conditions, radio communication can be maintained between expeditions at widely separated points on Mars.

At the altitudes at which Mariner IV passed Mars (the closest was 6118 miles), the spacecraft detected no significant change in magnetic forces or radiation intensities from the levels observed in interplanetary space. The lack of a magnetic field would indicate that Mars has no core of hot liquid metal as earth is theorized to have. The absence appears to coincide with the fact that no mountain



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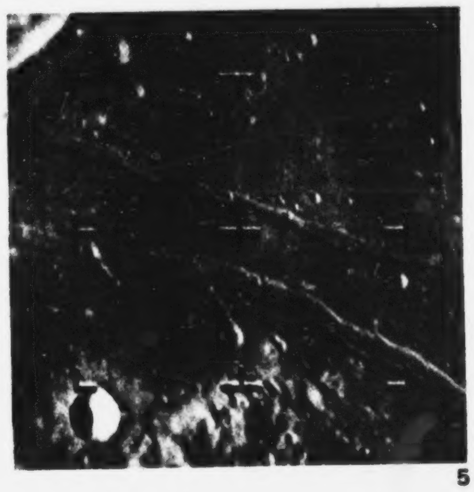

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1. *Ranger IX close-up of eastern edge of Crater Alphonsus. Note prominent rilles and dark material surrounding "halo" craters.*

2. *The moon seen through a telescope on earth.*

3. *Space surrounding earth as told man by his satellites. The geomagnetic field is earth's magnetic field. The magnetopause is the outer boundary of the geomagnetic field.*

4. *Ranger VII close-up of the moon. A cluster of craters dots a lunar ray. Lunar rays appear from earth as whitish lines radiating from some large craters.,*

5. *Ranger VIII close-range photography shows two rilles that look somewhat like a divided superhighway on earth. Rilles are long deep depressions on the moon's surface.*

1

2

chains, great valleys, and what could be continental masses could be recognized in the close-ups of Mars. These physical features are believed to be produced by stresses within a planet. Such stress is usually associated with a molten core.

Astronomers in observatories on earth have discerned what appears to be frost around the Martian polar regions. Mariner IV pictures reveal comparable light-colored substances around the rims of some Martian craters. Some scientists say that if this is frost, it turns directly to vapor and then back again to frost without becoming water. *Mariner IV was not designed to determine whether there is life on Mars.*

Measurements from earth observatories indicate that the temperature at the Martian equator ranges from 50 degrees Fahrenheit at noon to 90 degrees below zero Fahrenheit at night. Such a temperature range is not prohibitive to life as known on earth.

Mars has seasons like those of earth, and its surface appears to change color with the seasons. The changes correlate with increases and decreases of the bright polar caps which are thought to be made up of thin layers of frost. The darkening of the surface observed when the polar caps grow smaller could indicate vegetation responding to moisture.

VENUS — A GLOOMY DESERT The orbit of Venus, inside that of the earth, at times brings the cloud-covered planet to within 26 million miles, nearest to the earth of all the planets.

However, man has never viewed this planet's surface.

Venus is enveloped by an apparently unbroken cloud mass that has blocked attempts at direct visual observation of the planet's surface. Knowledge of Venus has largely been dependent on analysis of radar echoes, sunlight reflection, and natural radio emissions from a distance of more than 26 million miles.

On December 14, 1962, NASA's Mariner II spacecraft achieved a significant breakthrough in advancement of knowledge about Venus by making the first relatively closeup study of the planet, flying as near to it as 21,645 miles. Analyses of data from Mariner and information from earth-based studies have indicated that Venus may be a gloomy, lifeless desert.

Mariner indicated that the temperature of Venus' surface may be as hot as 800° Fahrenheit. This temperature is hot enough to melt lead and precludes the possibility of life like that on earth.

The Venusian clouds, that start 45 miles above the planet's surface and rise to about 60 miles, have temperatures of 200° F. at their base; —30° F. at their middle level; and —60° F. at their upper level. Mariner detected no openings in the clouds.

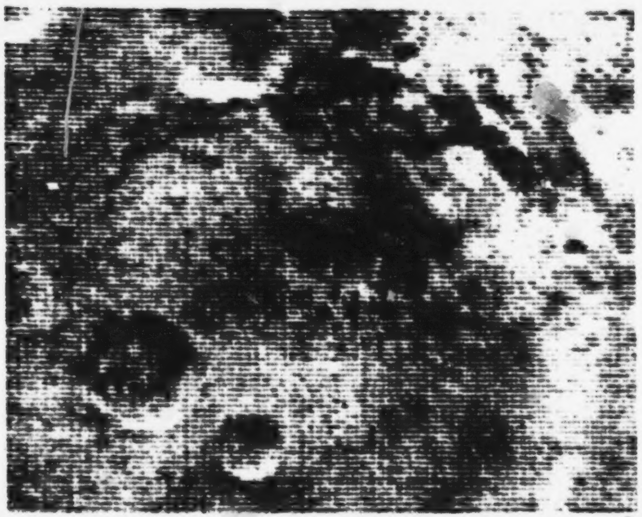
Analysis of spectroscopic data obtained by earth-

1. Craters with what appear to be frost-covered rims are visible in this Mariner IV close-up of Mars.

2. The horizon of Mars as seen from Mariner IV.

3. This Mariner IV close-up of Mars shows an older crater about 75 miles in diameter whose dimly visible rim incloses younger more sharply defined craters.

4. Mars through a telescope on earth.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based telescopes indicates that carbon dioxide is a constituent of the Venusian atmosphere. Moreover, there are indications that the Venusian atmosphere is 10 to 30 times denser than earth's. One theory holds that these atmospheric conditions contribute to the planet's high temperature by creating a greenhouse effect in which the sun's heat reaches the planet's surface but is hindered in reradiation to space.

Ground-based radar studies provide evidence that each Venusian day or night lasts more or less 112½ earth-days, and that on Venus, the sun rises in the west and sets in the east. Scientifically speaking, Venus appears to rotate every 249 days with respect to the sun and backward with respect to earth.

Ordinarily, because of Venus' indicated slow rotation, its night side should get very cold and its day side very hot. However, Mariner did not find any appreciable temperature difference on the planet. This suggests that the planet's atmosphere must be circulating vast quantities of heat from the day to the night sides. Such a massive heat transfer could generate searing winds that lash the planet's scorching surface.

Some radar reflections from Venus are characteristic of those made by sand or dirtlike material. If sand covers the surface of Venus, the high winds could create sand storms of tremendous proportions.

ASTEROIDS, COMETS, AND METEOROIDS Astronomers believe that the asteroids, sometimes called minor planets, number in the tens of thousands. The largest asteroid, Ceres, is 480 miles in diameter. Others are much smaller. Many are too small to be observed even with the best telescopes.

The asteroids are believed to be the remains of one or more larger planets. They revolve around the sun in the same direction as the planets. Sometimes, their orbits vary markedly from their general location between Mars and Jupiter. For example, the asteroid Icarus has an orbit which swings in as close to the sun as 18.5 million miles. In 1937, Hermes plunged to within 500,000 miles of earth. Astronomers believe that asteroids are solid and rocky in nature. Comets, on the other hand, appear to be mostly gaseous with a small solid core.

The orbits of comets around the sun are extremely elliptical. Some of their orbital periods (time for one complete circuit of the sun) are as great as hundreds of years. The most famous comet, Halley's, has a period of 76 years.

The nature and origin of comets are still a scientific mystery. However, a typical comet, as viewed from earth, usually includes a somewhat spherically shaped head and a long tail. The head consists of the coma and nucleus. The coma is the glowing gas around the nucleus that gradually stretches out to form the tail. The nucleus, which is not visible, is believed to be a mixture of ice, dust, and minerals. It is believed that as a comet approaches the sun, it is lit up by solar radiation.

A comets' tail always points away from the sun whether the comet is speeding to or from the sun. It is believed that the solar wind—the constant rush of hot electrified gases from the sun's surface—drives the extremely thin gases forming the tail into the direction opposite from the sun.

Meteoroids are relatively unclassified pieces of matter, larger than atoms and smaller than asteroids, speeding through space. They range in size from the rare massive chunks to microscopic. Explorer XVI, the first NASA satellite instrumented exclusively for meteoroid study, proved that even the microscopic meteoroids (micrometeoroids) can puncture thin metal surfaces. Studies have been continued with later meteoroid satellites, including Explorer XXIII and Pegasus I, II, and III.

Scientists debate the origin of meteoroids. Some suggest that they are the remains of colliding larger asteroids. Others say the meteoroids are residues of former comets. Still others hypothesize that meteoroids are the remnants of the massive cloud of dust and gas which coalesced into the solar system.

Meteoroids have three names, given to the same objects. They are called meteoroids in space. When they head through earth's atmosphere and glow due to atmospheric friction, they are referred to as meteors and sometimes called "shooting stars." Portions of meteors that survive the fiery trip through the atmosphere and strike earth are termed meteorites.

The 1965 Ikeya-Seki comet.

Space Probes & Satellites, General Principles

IV

SOME GENERAL PRINCIPLES Any manmade vehicle launched into space will move in accordance with the same laws that govern the motions of the planets about the sun, and the moon about the earth. ¶ Prior to the time of Copernicus, man generally accepted the belief that the earth was the center of the solar system. His efforts to explain the motion of the planets on this assumption failed. Copernicus pointed out that the difficulties in explaining the planetary movement observations disappeared if one assumed that the sun was the center of the solar system, and that the planets revolved about the sun. ¶ Years later, Galileo took up the defense of Copernicus' theory. With experiments such as the dropping of two different size masses from the Leaning Tower of Pisa, he started the thinking which led to our current understanding of the laws of motion. ¶ In the early 17th century, Johannes Kepler formulated three laws which described the motions of the planets about the sun. They are: 1. Each planet revolves about the sun in an orbit that is an ellipse. 2. The line from the center of the sun to the center of a planet (called the radius vector) sweeps out equal areas in equal periods of time. 3. The square of a planet's period of revolution is proportional to the cube of its mean distance from the sun. ¶ The above laws apply to the earth and its satellites as well as to the sun and its family of planets. The second law, as applied to satellites, means that they are constantly changing speed. A satellite reaches maximum velocity at perigee, the low point in its orbit. Its velocity falls to a minimum at apogee, the highest point in its orbit. In the illustration on page 26, the shaded areas are equal. The satellite takes the same time to go from 1 to 2 as from 3 to 4. ¶ Kepler's third law says generally that in the case of satellites, the greater their mean orbital altitude, the longer it takes them to go around the earth.

These laws, together with Sir Isaac Newton's laws of gravity and motion, are important to space missions. Through them, scientists can learn how the planets and other celestial bodies are moving. Through them, they can calculate the

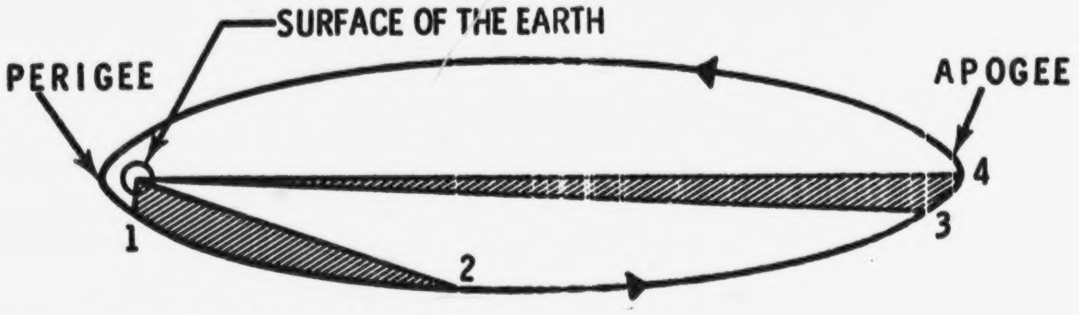


Illustration of Kepler's second law. See text.

flight paths of satellites and spacecraft sent to other planets and our moon.

GRAVITY Fundamentally, Newton's law of gravity can be described as follows:

All bodies, from the largest star in the universe to the smallest particle of matter, attract each other with what is called a gravitational attraction.

The strength of their gravitational pull is dependent upon their masses. The closer two bodies are to each other, the greater their mutual attraction.

Specifically, two bodies attract each other in proportion to the product of their masses and inversely as the square of the distance between them.

Earth, a body moving in space, has a gravitational pull. It pulls anything within its sphere of influence toward the center of the earth at increasing speed. This acceleration of gravity on earth at its surface is used as a basic measurement. It is known as 1 gravity or 1 "g".

Earth's gravitational influence is believed to extend throughout the universe, although the force weakens with distance and becomes virtually impossible to measure.

Any vehicle moving in space is subject to gravity. The vehicle, having mass, is itself a space body. Therefore it attracts and is attracted by all other space bodies, although the degree of attraction of distant bodies is too small to require consideration. A vehicle moving between earth and the moon would be influenced by both bodies, and also by the sun.

LAUNCHING A SATELLITE INTO ORBIT To place a satellite in orbit it is necessary to accelerate the vehicle to orbital velocity, a velocity at which its speed is offset by gravity so that it will go into orbit.

Since gravitational attraction decreases with the distance from the primary, a different orbital velocity is required for each distance from the primary.

For a satellite relatively close to earth, around 200 miles, the velocity required is about 17,500 miles per hour.

A vehicle placed in orbit as far away as the moon (roughly 240,000 miles) would need only to have an orbital velocity of about 2000 miles an hour.

This does not mean that attainment of the far-out orbit would be easier. Considerable additional force must be used to push a satellite out to that distance.

WHAT KEEPS A SATELLITE UP? As indicated above, satellites are subject to the same physical laws that govern motions of all bodies in space. These include not only Newton's laws of gravity and Kepler's laws of planetary motion but also Newton's laws of motion.

Newton's first law of motion states that a body remains at rest or in a state of motion in a straight line unless acted upon by an external force. Obviously, the external force drawing the satellite from a straight path is earth's gravity.

A part of Newton's second law of motion is that a force acting upon a body causes it to accelerate in the direction of the force. For one thing, this means that the pulling force of earth's gravity causes the satellite to fall toward earth.

What occurs with a satellite is that gravity to a degree has overcome the kinetic energy, or energy of motion, that tends to move the satellite in a straight line. Therefore, the satellite veers toward earth.

However, the satellite's kinetic energy is pushing the satellite forward every second that gravity is drawing the satellite inward. The satellite has sufficient kinetic energy so that its downward curving path continually misses or overshoots the earth. As a result, the satellite's motion is an elliptical or circular orbit around earth.

HOW A SATELLITE IS MADE TO "STAND STILL" Several satellites have been launched and maneuvered so that they appear to stand still over one location on earth. Among these are NASA's Syncom III experimental communications satellite and Early Bird I, a commercial communications satellite of the Communications Satellite Corporation.

Actually, these satellites are not stationary but moving at a speed of about 6875 miles per hour. The earth's equator more than 22,000 miles below them is moving at slightly more than 1000 mph. The relationships of the satellites to points on the earth's surface may be likened to those of racers on a circular track. The competitor in the outside lane has to run faster just to keep abreast of the one on the inside lane.

The phenomenon of the satellite that stands still over a point on earth is due to physical laws governing motions of objects in space. It is an application of Kepler's third law (see beginning of this chapter). As extended and generalized, the law says that a satellite's period of revolution (time to go around a planet) increases with its mean orbital altitude.

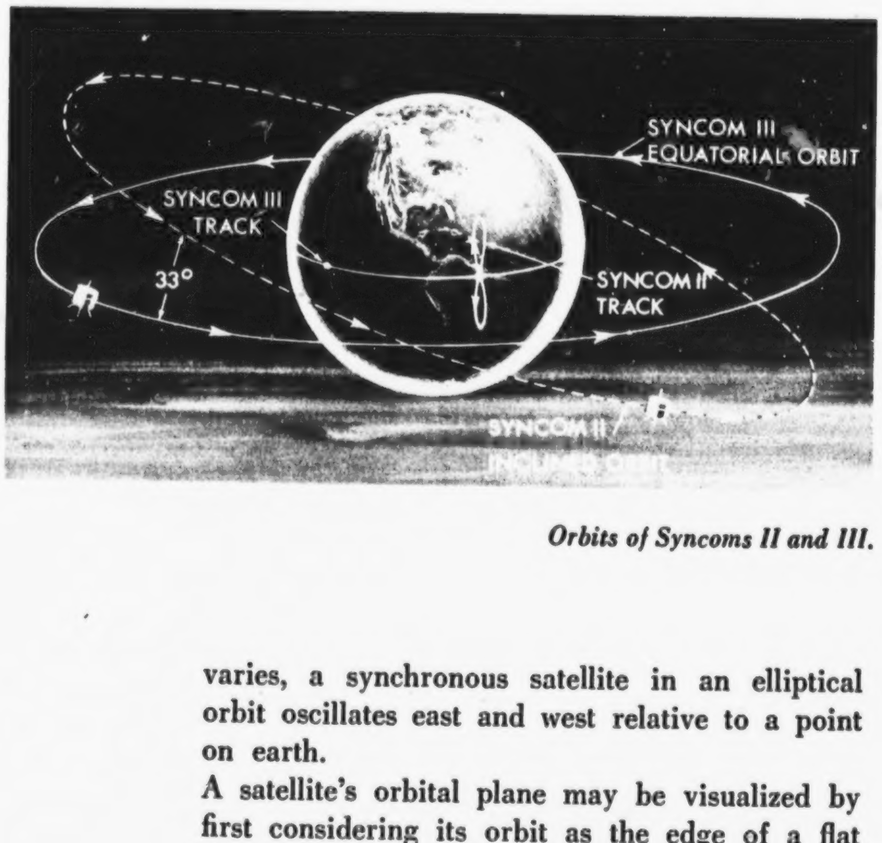
For example, the manned Gemini spacecraft orbited earth at altitudes from about 100 to approximately 160 miles. Their velocity was about 17,500 miles per hour. Their period of revolution was roughly 1½ hours. Because the earth takes about 24 hours to rotate completely around its axis, the Gemini spacecraft moved from west to east relative to earth's surface.

The moon has a mean altitude of 238,857 miles, a velocity averaging 2287 mph, and a period of revolution of 27 days, 7 hours, and 43 minutes. Because the moon's period of revolution is so much longer than the earth's period of rotation, the moon appears from earth to move from east to west. Its course in space actually is in the same general direction as Gemini.

It follows that at some altitude a satellite's period of revolution is the same as the earth's period of rotation. This altitude is about 22,235 miles. A satellite with this kind of altitude is called a synchronous (same time, literally) satellite.

To be stationary, however, the satellite must not only have a synchronous orbit but also a circular orbit lying in the plane of the equator.

The necessity for a circular orbit stems from Kepler's second law. Generally, this law says that a satellite in an elliptical orbit is always changing speed, reaching maximum velocity at perigee (lowest altitude) and minimum velocity at apogee (highest altitude). As a result, because its speed



Orbits of Syncoms II and III.

varies, a synchronous satellite in an elliptical orbit oscillates east and west relative to a point on earth.

A satellite's orbital plane may be visualized by first considering its orbit as the edge of a flat plate bisecting earth. This imaginary plate is the orbital plane.

When this plane is so positioned that part of it coincides with the equatorial plane (the equatorial plane can be imagined as a flat plate whose rim is the equator), the plane is said to lie in the plane of the equator. A satellite with such an orbital plane is said to be in an equatorial orbit. A satellite in a circular equatorial orbit at an altitude of approximately 22,235 miles would appear to hang motionless over a point on earth.

If the orbital plane of a synchronous satellite intersects rather than lies in the plane of the equator, the satellite is described as in inclined synchronous orbit. Instead of standing over one spot on earth, the satellite moves north and south of the equator, making a ground track like a slender figure 8.

ESCAPE VELOCITY A spacecraft sent to another planet or the moon must achieve escape velocity; that is, must overcome the pull of earth's gravity. This is done by accelerating the vehicle to a given speed. Since the force of earth's gravity declines with distance from the center of the earth (as noted before), the minimum speed required to overcome gravity varies.

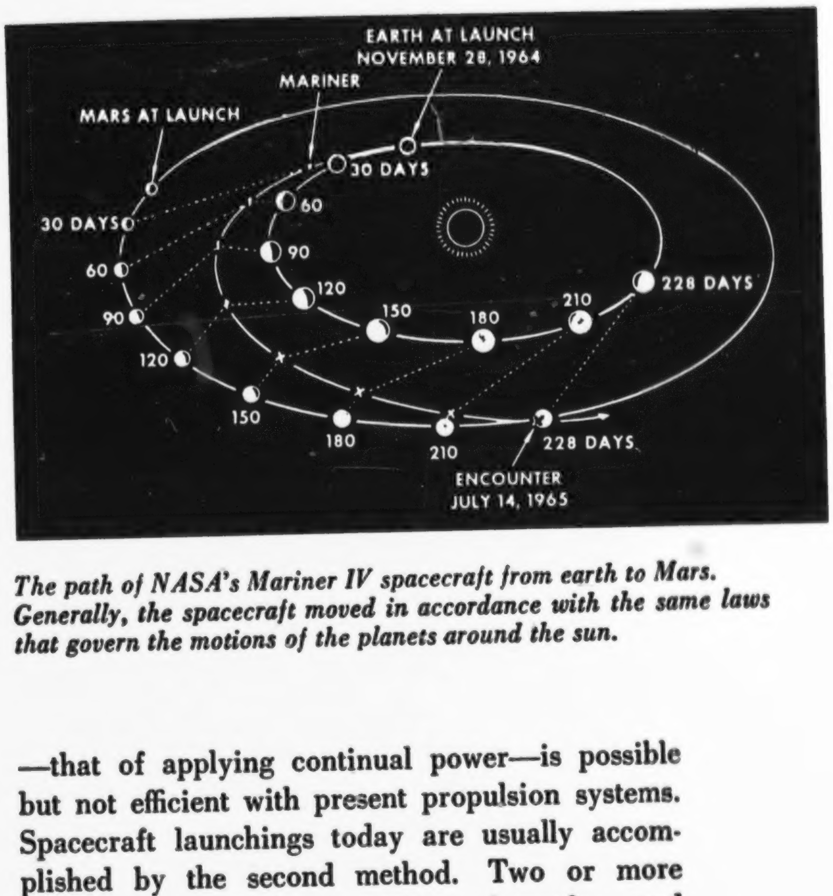
At or near the earth's surface, the speed required to overcome gravity is slightly more than 7 miles a second, or about 25,000 miles per hour. At an altitude of 500 miles, the speed needed to escape earth drops to 23,600 miles per hour. At a 5,000-mile altitude, the required speed is 16,630 miles per hour.

The attainment of escape velocity does not mean that the spacecraft is free of earth's gravitational influence (which extends to infinity). It means that even without additional power, the craft will not fall back to earth.

Imagine a launch vehicle rocketing a spacecraft from earth. The rocket follows an elliptical path. If its velocity reaches 25,000 mph, the ellipse does not close and the spacecraft completely escapes from earth. As it races into space, the spacecraft may be slowed down by earth's gravity, but it will continue outward—until it becomes subject to the sun's gravity—and never return to earth.

Launching a spacecraft into an escape trajectory is somewhat analogous to rolling a ball up a smooth, frictionless hill whose slope is continuously decreasing. (The slope of the hill compares to the force of gravity.) If the ball is not rolled fast enough, it will gradually slow until its velocity is exhausted. At this point it will momentarily pause before rolling back down hill, arriving at the bottom at the same velocity at which it left. There are several ways to succeed in getting the ball up the hill: (1) throw it with greater initial force; (2) carry it part way up the hillside before throwing; or (3) apply continual force until the top is reached.

Similarly—in space exploration a vehicle may be launched into space by application of the same principles mentioned above. As in (1) we can provide sufficient initial thrust to accelerate a rocket to 25,000 miles an hour, total escape velocity. It is possible to do this with a single-stage vehicle if we provide it with sufficient power to give it the thrust necessary before burnout. The second method (2) involves using a rocket to get through the lower atmosphere while reserving additional rockets for later stages of the flight through the upper and less dense atmosphere and into space. The third method of the analogy (3) —that of applying continual power—is possible but not efficient with present propulsion systems. Spacecraft launchings today are usually accomplished by the second method. Two or more rockets are stacked, one on top of another, and each of these stages fired in sequence. The velocity increases because each succeeding rocket before firing is traveling with the velocity achieved by the preceding stage. In addition, the gravitational attraction is less because of the altitude already reached by the earlier stages. Lack of drag from atmospheric friction at high altitudes also provides an advantage.



The path of NASA's Mariner IV spacecraft from earth to Mars. Generally, the spacecraft moved in accordance with the same laws that govern the motions of the planets around the sun.

Scientific Satellites & Sounding Rockets

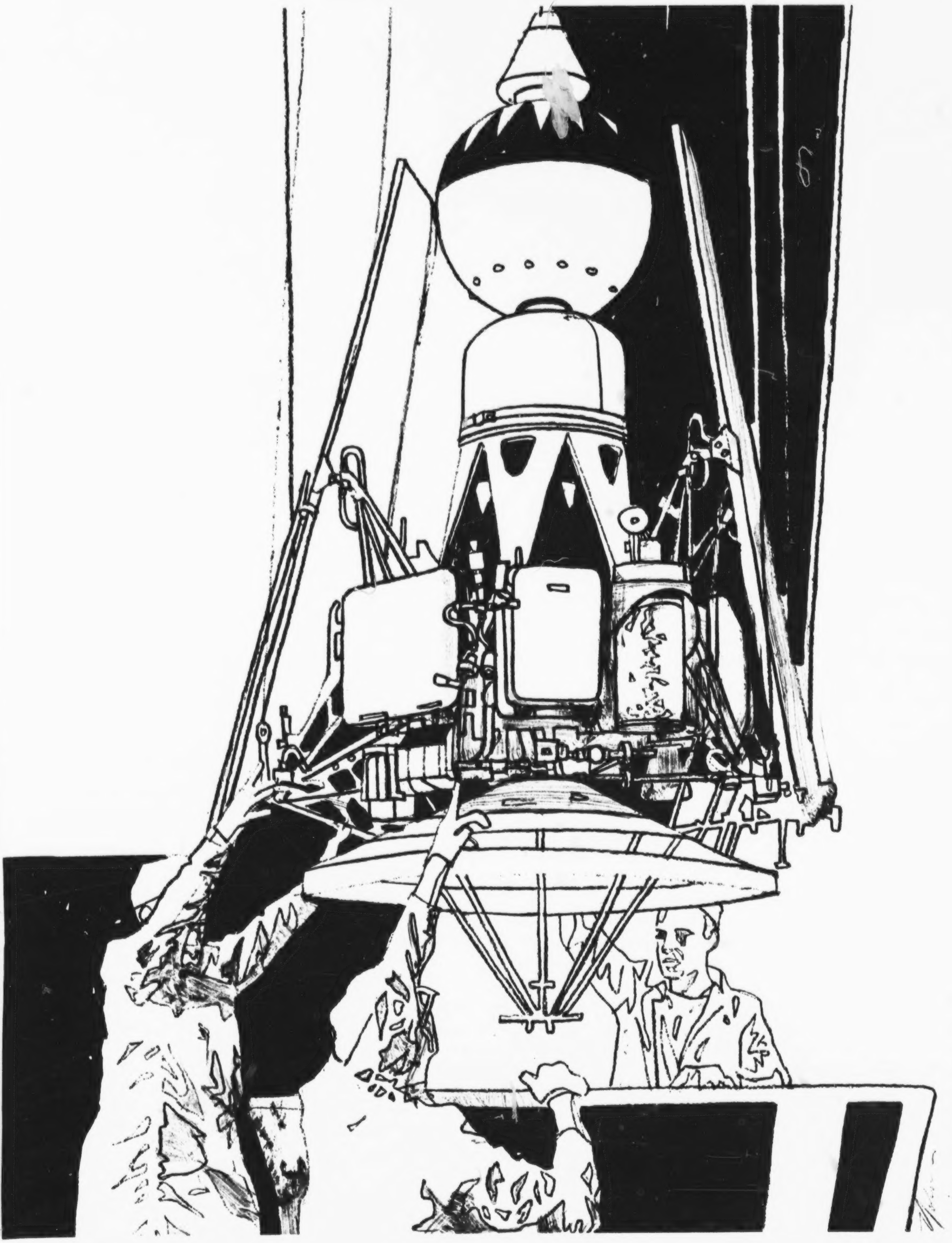
V

Numerous satellites and sounding rockets, equipped with various kinds of instruments, are measuring phenomena near and distant from earth. They are providing a wealth of data on space and have added to knowledge about the earth itself. This chapter describes the Nation's scientific satellites and sounding rockets and presents some of the advances in knowledge that they have made possible.

EXPLORERS Explorers comprise the largest group of satellites in the United States space program. Explorer I, launched February 1, 1958, was the Nation's first satellite. It made one of the most significant contributions of the Space Age, confirming existence of the previously theorized Van Allen Radiation Region—a zone of intense radiation surrounding the earth. ¶ Generally, Explorers are small satellites carrying a limited number of experiments. Their orbits vary to serve the particular purposes of the expeiments. Their designs also differ. ¶ Explorers have been put into orbit to: • Measure the thin wisps of air in the upper atmosphere, to determine air density by latitude and altitude. Example: Explorer XXIV. • Provide data on the composition of earth's ionosphere, including the presence of electrons, which enable the ionosphere to bounce back certain radio waves, thus making possible long range radio communications on earth. Example: Explorer XXXI. • Study the composition, density, pressure, and other properties of the upper atmosphere. Example: Explorer XVII. • Provide information on micrometeoroids (small particles of matter in space). Example: Explorer XXIII. • Measure the small variations in earth's gravity field and fix more precisely the locations of points on earth. Example: Explorer XXIX. *Interplanetary Explorers, such as Explorer XVIII, are described in another part of this chapter.*

NASA's University Explorer program offers universities the opportunity and challenge to design and build complete payloads *(instruments for experiments)* for Explorer satellites.

VANGUARD Project Vanguard was inaugurated as part of the American



program for the IGY. The first Vanguard satellite went into orbit on March 17, 1958.

Among the valuable data acquired from this satellite was information regarding the relatively slight but significant distortion referred to as the "pear shape" of the earth. Two other Vanguards were successfully launched in 1959 in this now completed program. Vanguards have provided valuable information on earth and its space environment, including such phenomena as earth's magnetic field, the Van Allen Radiation Region, and micrometeoroids—microscopic particles of matter larger than atoms and molecules—speeding in earth's vicinity.

INTERNATIONAL SATELLITES These are joint projects of mutual interest carried out by scientists of the United States and other countries in line with policies set down in the Space Act of 1958. By 1966, 14 such cooperative satellite projects with five nations were contemplated, in progress, or completed.

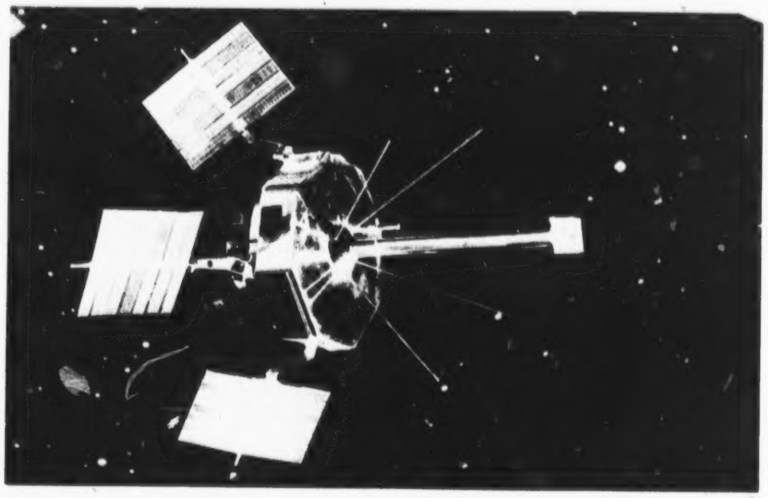
In some cases, experiments developed by other nations are included in satellites made and launched by the United States. In others, both experiments and satellites are built by the other nations and the United States provides the launch vehicles, launch facilities and other supporting effort. In addition, experiments from other nations sometimes are selected in competition with domestic proposals for inclusion on NASA satellites.

ARIELS / Ariel I, a cooperative project with the United Kingdom, was the world's first international satellite. It was launched by NASA, April 26, 1962, with experiments built by the United Kingdom. It has provided information on the variation of cosmic rays with earth latitude and intensities of radiation in the Van Allen Radiation Region. Ariel I information also has enabled scientists to correlate solar data with ionospheric properties.

Ariel II, containing three British-built experiments, was launched March 27, 1964, to measure galactic radio noise, vertical distribution of ozone in the upper atmosphere and the number and size of micrometeoroids. A third British satellite is planned to extend the studies.

ISIS / These are a series of Canadian-built satellites that are launched by the United States. The initials stand for International Satellites for Ionospheric Studies. The first ISIS satellite, named Alouette II after it achieved orbit, was launched November 28, 1965. Three additional ISIS craft are planned. Alouette I was launched on September 29, 1962, prior to establishment of the ISIS program. The Canadian Alouette I was the first satellite built by a nation other than the United States and the Soviet Union.

SAN MARCO / On December 15, 1964, an Italian ground crew launched the Italian satellite San Marco I from NASA's Wallops Station, Virginia. The purpose of the experiment was to test the technology and provide experience for launching a later similar satellite from a floating platform.



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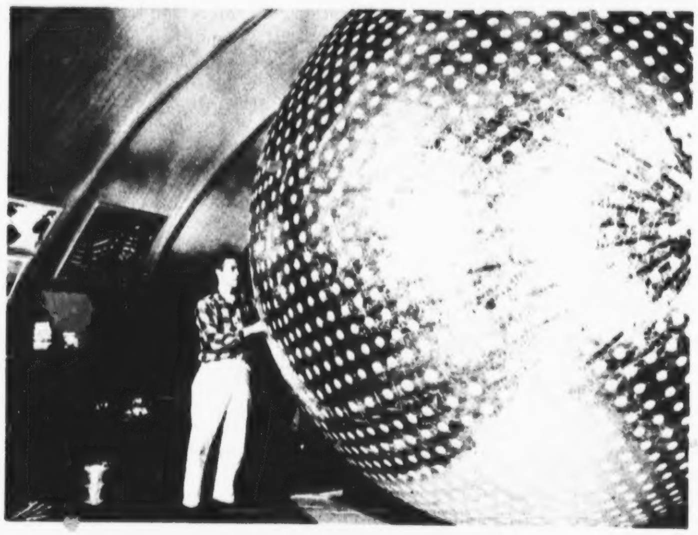

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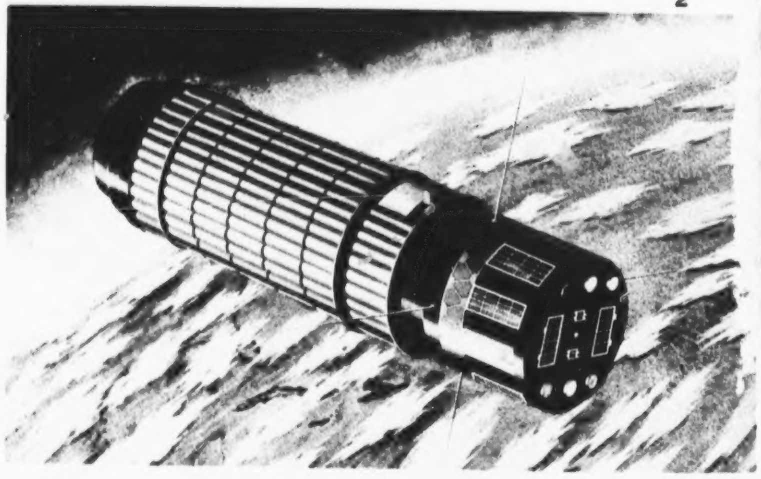

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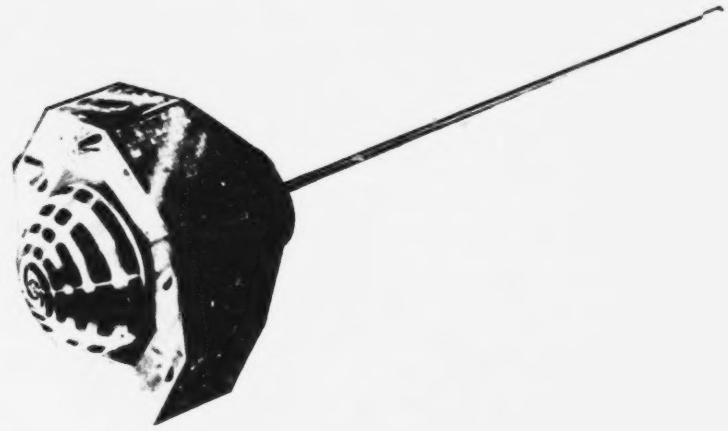
The platform would be towed to the Indian Ocean and positioned for launching San Marco II into an equatorial orbit. San Marco satellites are instrumented to measure air density and investigate characteristics of the ionosphere that affect long-range radio communication.

FR-1A / This French-built satellite was launched by the United States on December 6, 1965. It is designed to study the ionosphere. The information it provides is expected to contribute to the improvement of long distance radio communication on earth. (France is also launching French satellites with rocket boosters made in France.)



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1. *Explorer XXVI.*
2. *Explorer XXIV.*
3. *Explorer XXIII.*
4. *Explorer XXXI.*
5. *Explorer XVII.*
6. *Explorer XXIX.*
7. *Explorer 1.*

ESRO / The *E*uropean *S*pace *R*esearch *O*rganization was set up by a group of nations to build, launch and monitor satellites and sounding rockets. ESRO members are Belgium, Denmark, France, Federal Republic of Germany, Italy, Netherlands, Spain, Sweden, Switzerland, and United Kingdom. The organization is arranging with the United States Government to set up its own tracking station in Alaska. ESRO and NASA have made an agreement under which the ESRO I and II satellites would be orbited by NASA launch vehicles.

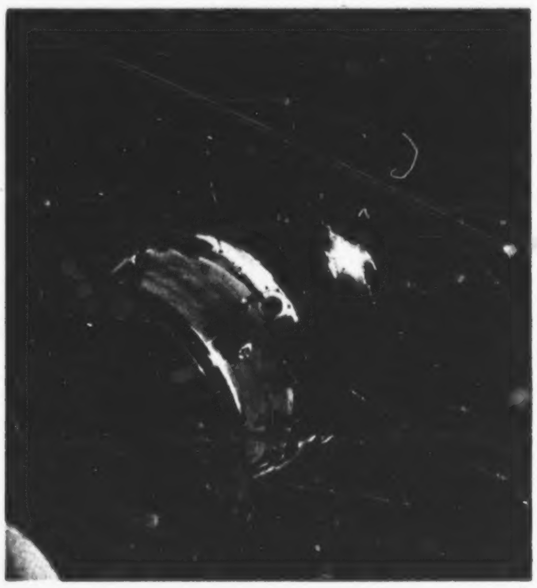
INTERNATIONAL PROGRAMS *The United States conducts a broad program of international cooperation in space research. Some 70 foreign countries and jurisdictions participate with the United States in joint satellite projects contributing their experiments to NASA satellites, launching sounding rockets, ground-based support of scientific satellites, participation in world-wide tracking networks, and programs of technical training, education, and visitor exchange.*

INTERPLANETARY EXPLORERS Interplanetary Explorers are a special class of Explorers to provide data on radiation and magnetic fields between the earth and moon. The information will be of value to science and contribute to planning for the Apollo program to land American explorers on the moon. The first Interplanetary Explorer, named Explorer XVIII, provided data indicating that the earth's magnetic field was shaped more like a tear drop than like the familiar cluster of iron filings around a bar magnet. The magnetic field apparently is pushed into this kind of shape by the solar wind, which consists of hot electrified gases rushing from the sun's surface. The impact of the speeding solar wind against the earth's magnetic field was shown by Explorer XVIII data to produce a shock wave. A series of *Lunar-Anchored Interplanetary Explorers* is being planned for launch into orbit around the moon. These spacecraft will report on gravity, radiation, magnetic fields, micrometeoroids, and other phenomena in the lunar environment. This information too will advance both scientific knowledge and planning for manned exploration of the moon.

ORBITING ASTRONOMICAL OBSERVATORY (OAO) Man's study of the universe has been narrowly circumscribed because the atmosphere blocks or distorts much electromagnetic radiation (X-rays, infrared rays, ultraviolet rays) from space. These emissions can tell much about the structure, evolution, and composition of celestial bodies. OAO will make it possible to observe the universe for extended periods from a vantage point above the shimmering haze of the lower atmosphere that contains 99 percent of earth's air.

OAO will see celestial bodies shining steadily against a black background. It will clearly delineate features which from the earth are either fuzzy or indistinguishable. Astronomers predict that OAO will furnish a wealth of new knowledge about the solar system, stars, and composition of space.

OAO will be a precisely stabilized 3900 pound satellite in a circular orbit about 500 miles above the earth. It will carry about 1,000 pounds of experimental equipment such as telescopes, spectrometers, and photometers. The scientific equipment will be supplied to NASA by leading astronomers.



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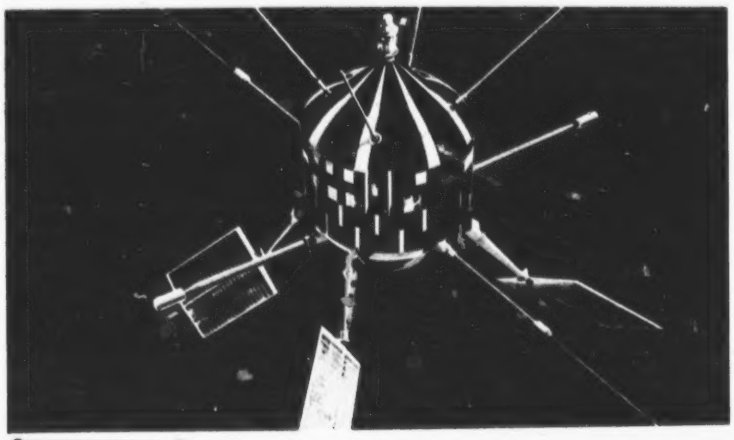

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The standardized[1] OAO shell, which will be employed for many different types of missions, will contain stabilization, power, and telemetry systems. Two silicon solar-cell paddles and nickel-cadmium batteries will furnish an average usable power supply of 405 watts.

The height of the satellite is about 10 feet with sunshade down. The satellite is about 21 feet wide with solar paddles extended. Width of the main body is about 7 feet.

ORBITING SOLAR OBSERVATORY (OSO) OSO is a series of satellites intended for intensive study of the sun and solar phenomena from a point above the disruptive effects of the atmosphere. The observatory is designed to carry such instruments as X-ray and Lyman Alpha spectrometers, neutron flux sensors, and gamma ray monitors. Like OAO, OSO scientific equipment is supplied NASA by leading astronomers.

The first of these observatories, OSO I, was launched March 7, 1962. From an approximately 350-mile altitude, nearly circular orbit, the 440-pound spacecraft pointed instruments at the sun with an accuracy comparable to hitting a penny a half mile away with a rifle bullet.

Data from OSO I have provided deeper insight into the functioning of the sun, and suggest that techniques could be developed for forecasting the major solar flares that flood space with intensities of radiation lethal to man and detrimental to instruments.

OSO I is about 37 inches high and 44 inches in diameter at the wheel-shaped section. OSO II, with an added capability for scanning the solar disc, was launched on February 3, 1965, to continue scientific studies of the sun.

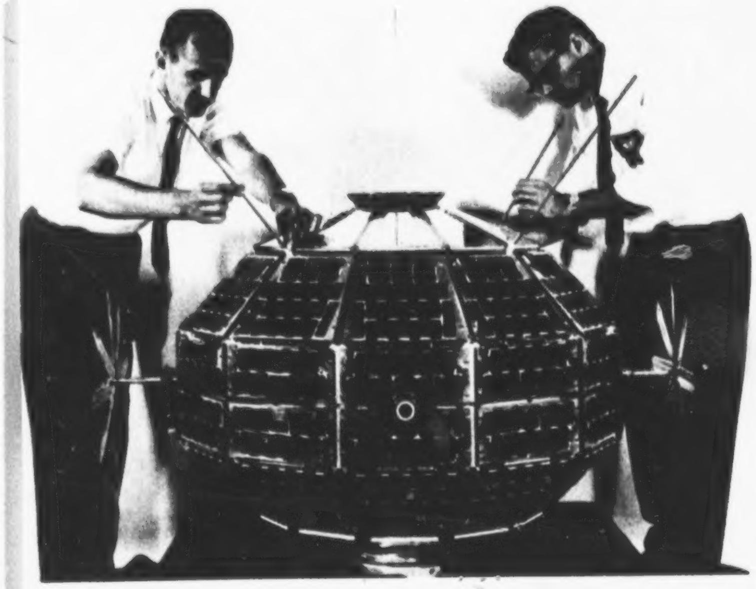
ORBITING GEOPHYSICAL OBSERVATORY (OGO) Orbiting Geophysical Observatories are designed to broaden significantly knowledge about the earth and space and how the sun influences and affects both. The approximately 1000-pound OGO furnishes many times the data provided by smaller scientific satellites such as the Explorers. For example, OGO I, launched September 4, 1964, and OGO II, launched October 14, 1965, each carry 20 different experiments as compared to the relatively few experiments of Explorer XVIII (8 experiments).

The principal advantage of OGO is that it makes possible the observation of numerous phenomena simultaneously for prolonged periods of time. This permits study in depth of the relationships between the phenomena. For example, while some OGO experiments report on the erratic behavior of the sun, others may describe concurrent fluctuations in earth and interplanetary magnetic fields, space radiation, and properties of the earth's atmosphere.

OGO is launched on a regular schedule into preassigned trajectories. When launched into an eccentric orbit (perigee about 150 miles, apogee about 60,000 miles) OGO studies energetic particles, magnetic fields, and other geophysical phenomena requiring such an orbit.

When launched into a low-altitude polar orbit (apogee about 500 miles, perigee about 140 miles), OGO is instrumented chiefly for study of the atmosphere and ionosphere, particularly over the poles.

1. *Vanguard's polished surface reflects Cape Kennedy, Florida.*
2. *Ariel II, British-U.S. satellite.*
3. *Canadian-built Alouette satellite.*



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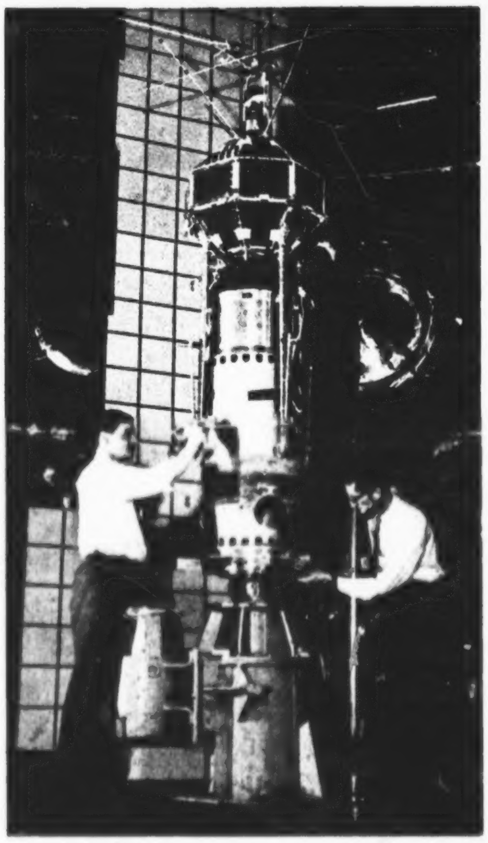
[1] A standardized satellite is a basic structure, complete with power supply, telemetry, data storage facilities, and other fundamental equipment. Its modular compartments are capable of carrying many different experiments on any one mission. Each of the standardized satellite's modules is a sample, plugged-in electronic building block. Thus the structure can be fabricated independently, with any experiment designed to fit one or more modules. Among other typical standardized satellites are the Orbiting Geophysical Observatory and the Orbiting Solar Observatory.

1

PEGASUS Named for the winged horse of Greek mythology, Pegasus satellites are among the heaviest and largest of U.S. spacecraft. Deployed in space, the great wings of the Pegasus satellites span 96 feet while the center section, resembling the fuselage of an airplane, is 71 feet long. The wings are designed to report punctures by micrometeoroids, tiny particles of matter speeding through space. Data from Pegasus satellites not only have advanced man's understanding of space but are aiding him in design of large craft intended for prolonged missions in space. For example, the depth and frequency of penetrations



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1. *Interplanetary Explorer satellite.*

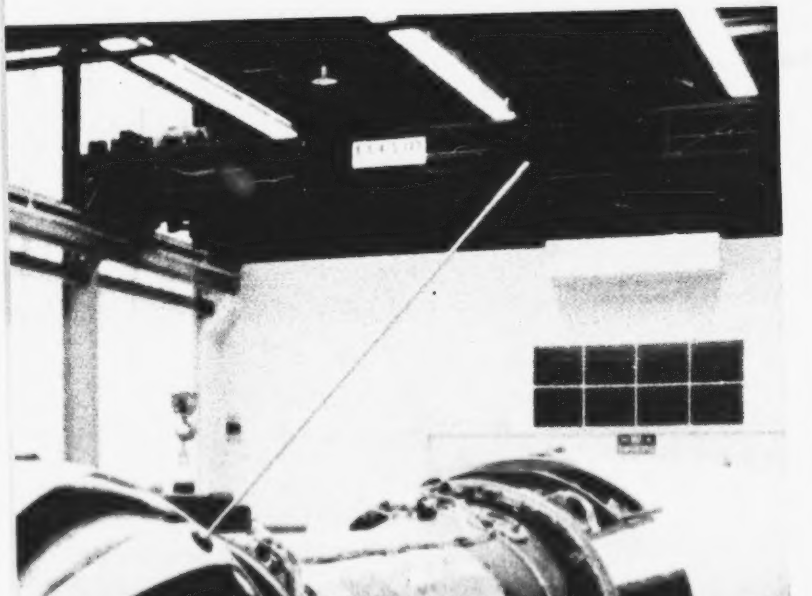
2. *Prototype of French FR-1 satellite is checked out.*

3. *Italian San Marco satellite, attached to U.S. Scout launch vehicle, is examined.*

reported by Pegasus satellites help engineers to design the walls of a spacecraft.

The Pegasus satellites present about 80 times the surface that was exposed to particle impact by prevous meteoroid study satellites such as Explorers XVI and XXIII. The three satellites in the Pegasus program were launched by Saturn I rocket vehicles on February 16, May 25, and July 30, 1965.

BIOSATELLITES The Biosatellites will carry into space a wide variety of plants and animals ranging from micro-organisms to primates. The experiments are aimed primarily at studying the biological effects of zero gravity, or weightlessness, weightlessness combined with a known source of radiation, and removal of living things from the influence of the earth's rotation. They are expected to contribute to knowledge in genetics, evolution, and physiology, and to provide new information about the effects of prolonged flight in space.



DISCOVERER Discoverer is a U.S. military satellite program that, since its inception on February 28, 1959, has provided valuable data in such areas as radiation, meteoroids, and air density in space near earth; and in aerospace medicine. A major contribution of the program was the development of the technology for mid-air recovery or sea recovery of packages sent from an orbiting satellite to earth.

The first sea recovery was a package from Discoverer XII. The reentry package was picked up on August 11, 1960. The first mid-air recovery of a package ejected from a satellite took place on August 18, 1960. The 300-pound recoverable package had been ejected from Discoverer XIV.

Discoverers have also tested components, propulsion, guidance systems, and other technology for space projects. The Discoverer program was a major factor in testing and perfecting the Agena rocket, the reliable upper stage for many space science launch vehicles. (The satellite's structure is built around the Agena.)

SOUNDING ROCKETS Man's early adventures into the atmosphere and space were with sounding rockets. The first were accomplished by early rocket societies in several countries and by Dr. Robert Goddard, an American. Sounding rockets may have one or more stages. Generally speaking, they are designed to attain altitudes up to about 4,000 miles and return data by telemetry or capsule recovery. Those designed for lower altitude may simply investigate geophysical properties of the upper atmosphere surrounding the earth. These have returned information on atmospheric winds, the earth's cloud cover, and the properties of the ionosphere. Higher altitude sounding rockets have sent back data on cosmic rays, the radiation belts, ultraviolet rays, solar flares, and many other phenomena.

Sounding rockets permit the performance of scientific studies in a vast region of the atmosphere too low for satellites and too high for balloons to reach. The area ranges from 20 to 100 miles in altitude. Another significant, but less known, value derived from sounding rockets is the in-flight development testing of instruments and other equipment intended for use in satellites. By first checking out the performance of these components during sounding rocket flights in the near-earth space environment, greater satellite reliability is assured and costly failures may be avoided. New experimenters from universities, industry and foreign organizations find the sounding rocket program a logical and inexpensive starting point for gaining experience in space science techniques. Another attribute is that sounding rockets provide scientists with instruments at the time and place needed. They require relatively little ground support equipment or launch preparations.

When instrumented payloads pass the 4,000 mile altitude they sometimes are called *geoprobes*. Examples of geoprobes are the P-21, launched October 19, 1961, and the P-21a, launched March 29, 1962, to measure ionosphere characteristics by day and by night. Both were carried to about 4,200 miles altitude by NASA Scout launch vehicles. Their results confirmed the existence of a helium gas region in the atmosphere wedged between a region where oxygen predominates and one where hydrogen is the dominant gas. *Explorer VIII, launched November 3, 1960, provided the first indication of the helium layer.*

Typical of sounding rockets employed in scientific programs are:

Aerobee / First fired November 14, 1947, Aerobee launchings include the solar beam experiment program to monitor background radiation from the sun during quiet periods of solar activity; studies of ultraviolet radiation of the stars and nebulae; gamma radiation studies; and many other scientific programs.

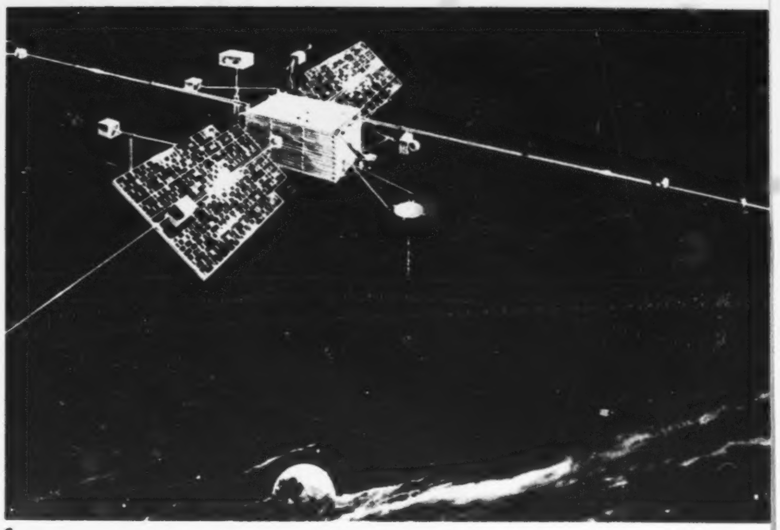


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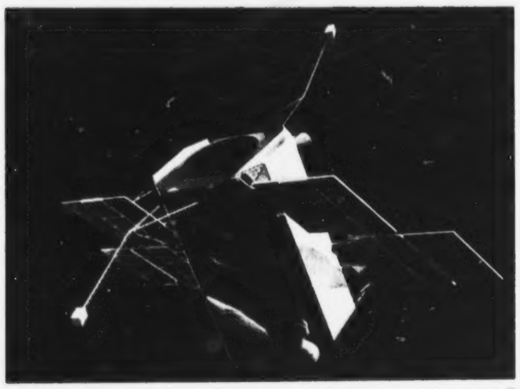
Table II—NASA SOUNDING ROCKETS

Name	Stages	Payload Weight (Pounds)	Operating Altitude (Miles)
Aerobee 150 and 150 A	2	150	130
Aerobee 300	2	50	200
Aerobee 350	3	150	250
Arcas	2	12	45
Argo D-4 (Javelin)	4	100	545
Argo D-8 (Journeyman)	4	130	1000
Astrobee 1500	2	130	1040
Nike-Apache	2	50	130
Nike-Cajun	2	50	90
Nike-Tomahawk	2	100	180

NIKE / With upper stages, the Nike has been employed largely in upper atmosphere experiments. In one experiment, a series of small grenades are ejected and exploded at intervals along the rocket's trajectory. The explosion's location is determined by radar and/or optical methods; the time of arrival of the sound wave front at the ground is measured by microphones. This information with appropriate meteorological data on the lower altitudes indicates wind and temperature as a function of altitude. Another kind of experiment releases a sodium vapor trail which glows orange in twilight along the upper portion of the rocket's trajectory. The deformations of this trail are recorded on time lapse photographs from which wind information is derived. A third method is the pitotstatic tube experiment by which atmospheric density, temperature, and wind data are derived from measurements of pressure during flight of the rocket.

ARCAS / These small meteorological sounding rockets provide information about the atmosphere at altitudes from about 20 to approximately 40 miles. The rockets eject such sensors as chaff,



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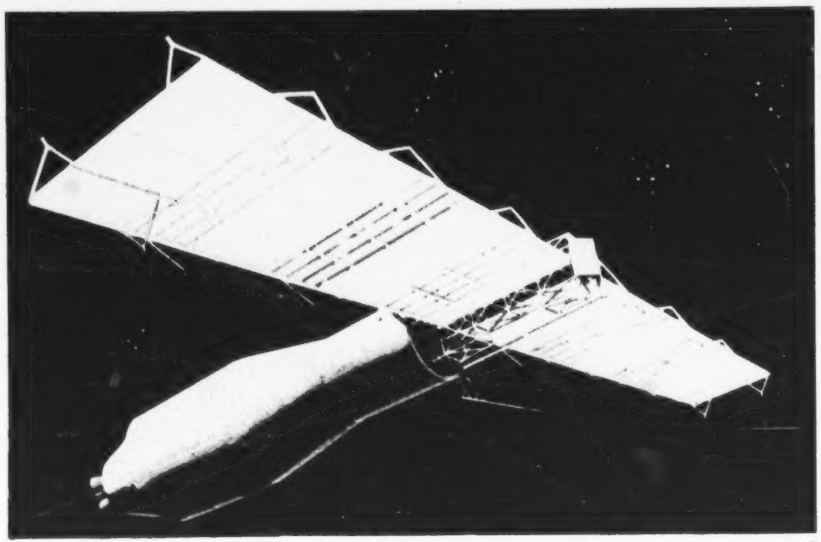

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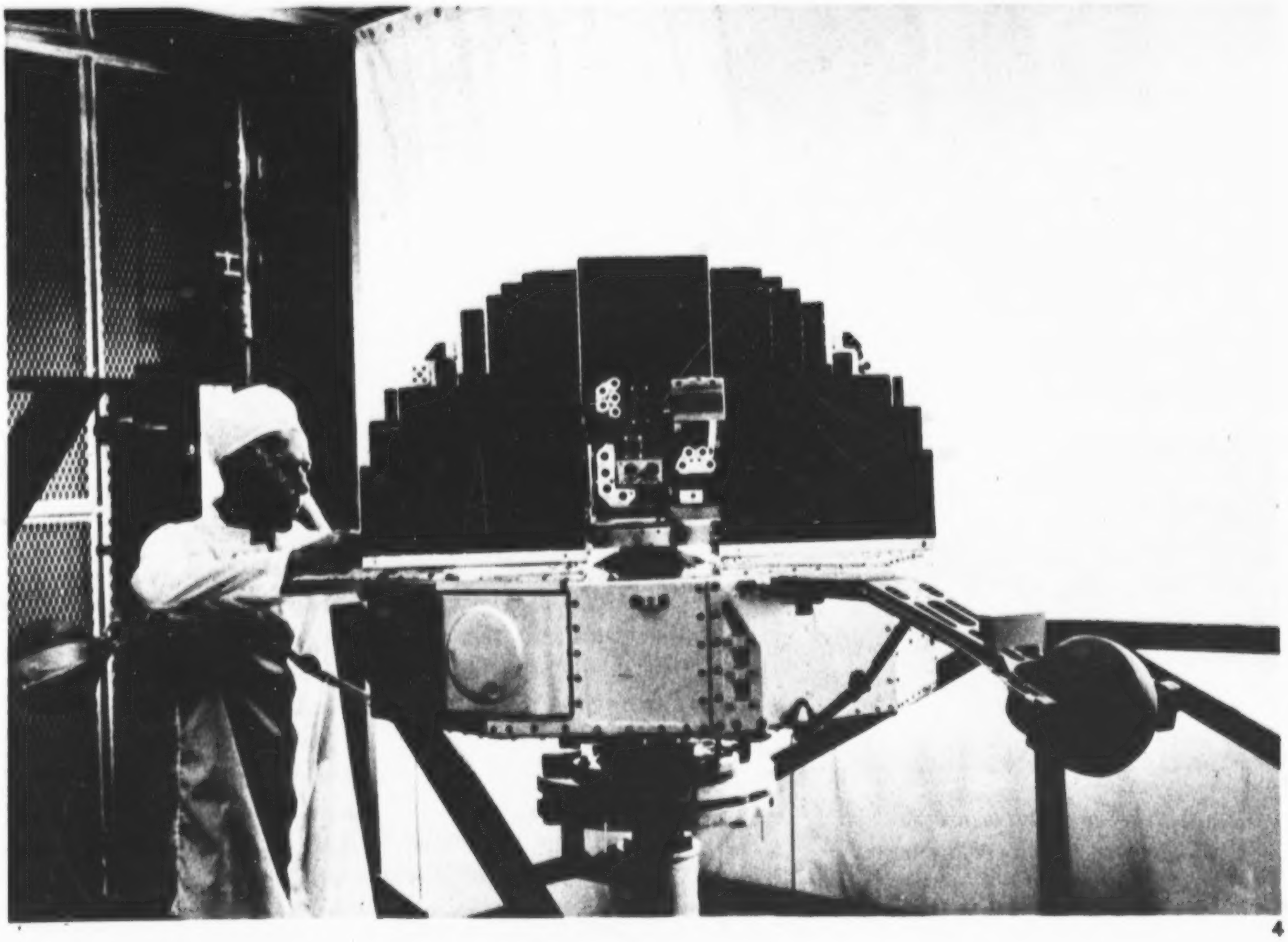
1. *Orbiting Geophysical Observatory.*
2. *Orbiting Astronomical Observatory.*
3. *Pegasus.*
4. *Technicians work on Orbiting Solar Observatory.*



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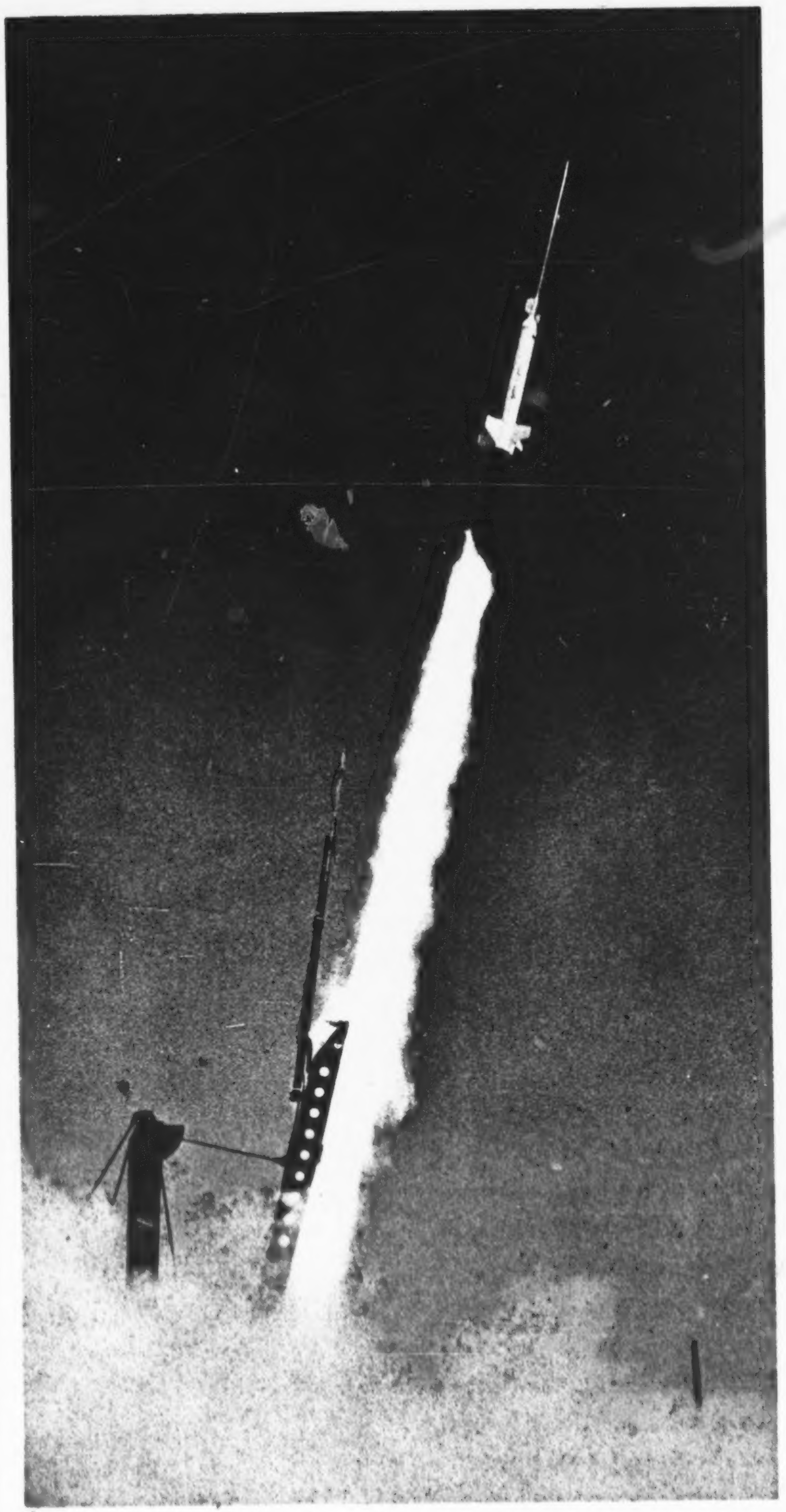
2

1. *Astrobee 1500 is launched.*
2. *Aerobee 150A sounding rocket is checked out prior to launch.*
3. *Nike-Cajun rocket is launched.*

parachutes, inflated spheres, and bead thermistors at the high points of their trajectories and these provide information about the atmosphere as they fall to earth. (The bead thermistor is in a package that radios its temperature information to earth. The chaff, parachute, and inflated sphere provide information on wind. The inflated sphere also provides information on air density.)

Sounding rockets can be used for space experiments ranging from study of weather to picking up the faint ultraviolet rays from distant stars. On May 30, 1965, Arcas sounding rockets were used in conjunction with high flying jet aircraft,



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instrumented balloons, and ground-based observatories to study a solar eclipse. An eclipse, among other things, presents an unusual opportunity to view the sun's atmosphere, or corona, which is normally masked by bright sunlight and to find out what happens to the earth's upper atmosphere, particularly the ionosphere, when solar radiation is abruptly curtailed.

Significant scientific discoveries made by study of data from sounding rockets include the fact that temperatures in the mesosphere, *an atmospheric layer 30 to 55 miles above earth,* are as much as 60 degrees higher in winter than in summer. They have also provided evidence of pronounced wind shears at altitudes above 40 miles. Wind shears refer to shifts in wind direction from altitude to altitude.

Sounding rockets have reported also the lowest temperatures ever measured for earth's atmosphere. U.S.-Swedish cooperative sounding rocket studies conducted from Swedish Lapland found temperatures as low as −143 degrees Centigrade *(—225 degrees Fahrenheit)* in the upper atmosphere.

The studies also solved the mystery of noctilucent clouds. Such clouds, existing at altitudes of about 60 miles and peculiar because they shine at night, appear to be composed of ice-coated dust particles.

NASA AND THE IQSY *NASA experimenters made many contributions to the IQSY (International Quiet Sun Year). The IQSY, which was conducted from January 1, 1964, to December 31, 1965, was a world-wide study of the sun and its effects.*

The program was a sequel to the IGY (International Geophysical Year). The IGY was a world-wide study of the sun and earth conducted in 1957 and 1958.

IQSY was conducted during a solar period when the sun was relatively free of solar flares, sunspots, and other eruptions. IGY was conducted during the period of maximum solar activity.

Comparisons of IGY and IQSY data and other studies are expected to increase understanding of the sun and its effects on earth.

NASA Explorer satellites, Orbiting Solar Observatories, Orbiting Geophysical Observatories, and the Mariner IV spacecraft launched toward Mars (see Chapter VII) provided data for IQSY. Four international satellites launched in cooperation with NASA provided scientific measurements: the Canadian Alouettes I and II, the French FR-1, and the Italian San Marco.

NASA studied the solar eclipse of May 30, 1965, by means of sounding rockets, balloons, aircraft, and other observations from land and sea.

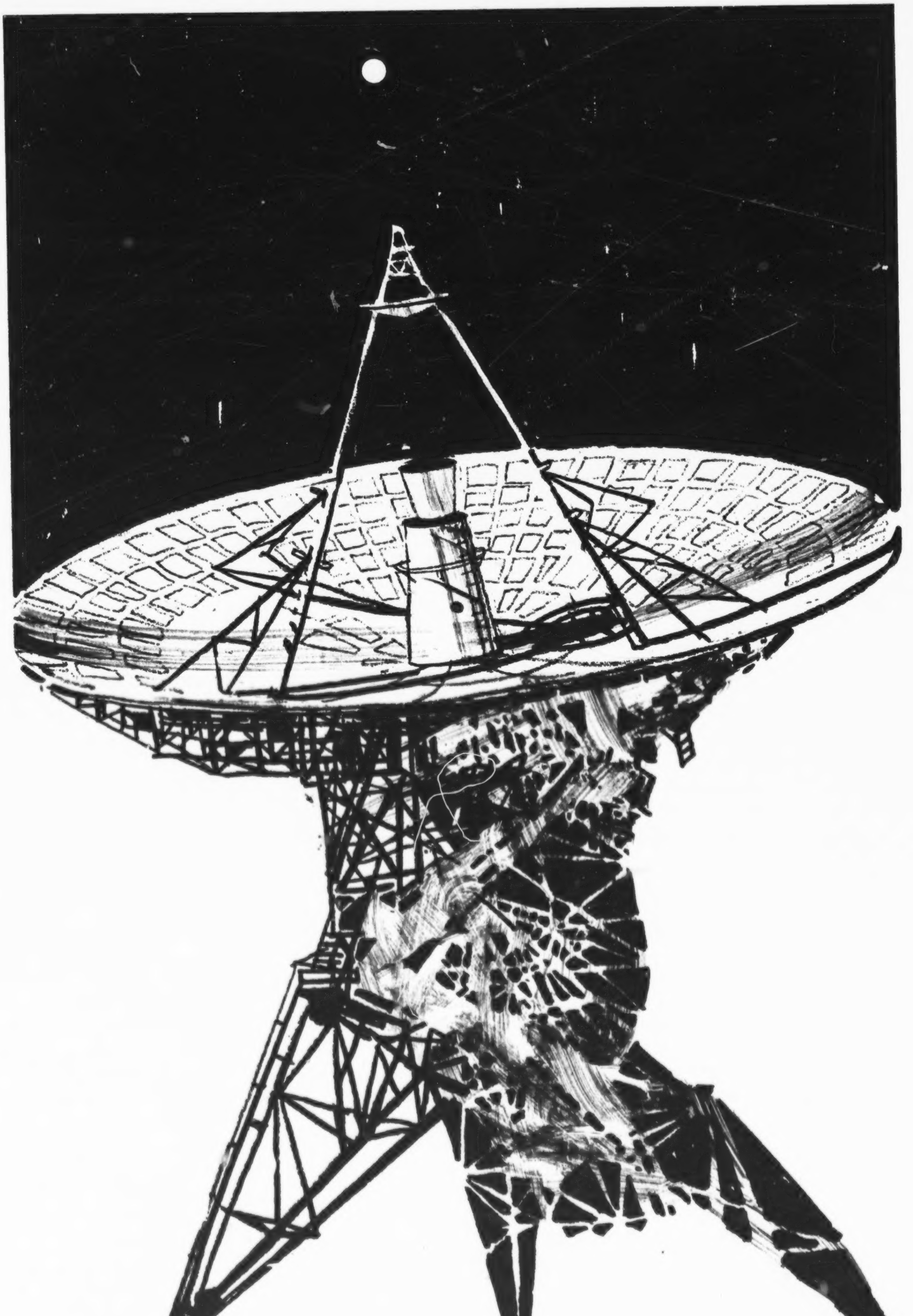
A feature of sounding rocket experiments during the IQSY was a three-month expedition in 1965 using the USNS "Croatan." During the period, nearly 80 sounding rockets were launched to study areas of the upper atmosphere that cannot be reached from land launch sites.

Applications Satellites

VI

Space technology is being turned to immediate practical use in two ways. One is identifying and making widely known the new processes and techniques developed in the space program which can stimulate creation of new industrial processes, methods, and products, and add new dimensions to everyday living. Another involves development of satellite systems for aid in such fields as weather forecasting, communications, and navigation.

ECHO Echo I, orbited on August 12, 1960, proved that it is possible to communicate between distant areas on earth by reflecting radio microwaves from a manmade satellite. Echo I is fabricated of aluminum-vapor-coated polyester film 0.0005 inch thick (about half the thickness of cellophane wrapping on a cigarette package). It is 100 feet in diameter and weighs 123½ pounds. Radio signals are literally bounced off the satellite from one point on the earth to another. ¶ Echo II, launched January 25, 1964, is 135 feet in diameter as tall as a 13-story building—and weighs 565 pounds. Made up of a laminate of aluminum foil and polymer plastic about 0.00075 inch thick, it is 20 times as rigid as Echo I. Echo II is the first satellite to be used in cooperation with the U.S.S.R. **RELAY** Project Relay demonstrated the feasibility of intercontinental and transoceanic transmission of telephone, television, teleprint, and facsimile radio signals via a medium-altitude (several thousand to 12,000 miles) active-repeater (radio-equipped) satellite. Two Relay satellites have been launched in this now completed program, one on December 13, 1962, and the other on January 21, 1964. Thousands of tests and public demonstrations of transoceanic and intercontinental communication were conducted via these experimental satellites. ¶ Among the noteworthy public telecasts were the unveiling of the Mona Lisa at the National Gallery of Art in Washington, D. C., the funeral of Pope John and the coronation of Pope Paul, the stirring telecast of President Kennedy signing a bill bestowing honorary American citizenship on Sir Winston Churchill, events surrounding the assassination of President Kennedy, the national political campaigns and



election of 1964, and the opening of the Winter Olympic Games of 1964 in Austria. Among the technological firsts in the program were live transpacific telecasts between Japan and the United States.

SYNCOM NASA's Project Syncom (for *syn*chronous *com*munication) demonstrated the feasibility of employing synchronous active-repeater satellites for global communication. Syncom satellites have been used in many experiments and public demonstrations. Among the latter was the telecast of the Olympic games from Japan to the United States in October 1964. Syncom III, launched August 19, 1964, is the world's first stationary satellite. (See Chapter IV, "Space Probes and Satellites—General Principles," on "How a Satellite Is Made To Stand Still.")

Syncom I, launched February 14, 1963, was placed in a nearly synchronous orbit but contact with the satellite was lost. Syncom II, launched July 26, 1963, was placed in an inclined synchronous orbit which crosses over rather than stays over the equator. As a result, Syncom II travels north and south but not east or west.

The Department of Defense has employed Syncoms II and III for communications within the Pacific and Indian Ocean areas. On March 31, 1965, NASA transferred Syncoms II and III and ground support equipment operated by NASA for the Syncom project to the Department of Defense. Under the transfer agreement, the Department of Defense continued to supply NASA with Syncom data of scientific or engineering interest.

TELSTAR Telstar—like Relay—was an experiment using active-repeater satellites in medium-altitude orbits. Because the two satellites differed in important structural and other features, they permitted comparison of different designs. This contributed to the acquisition of information needed to develop equipment for an operational communications satellite system.

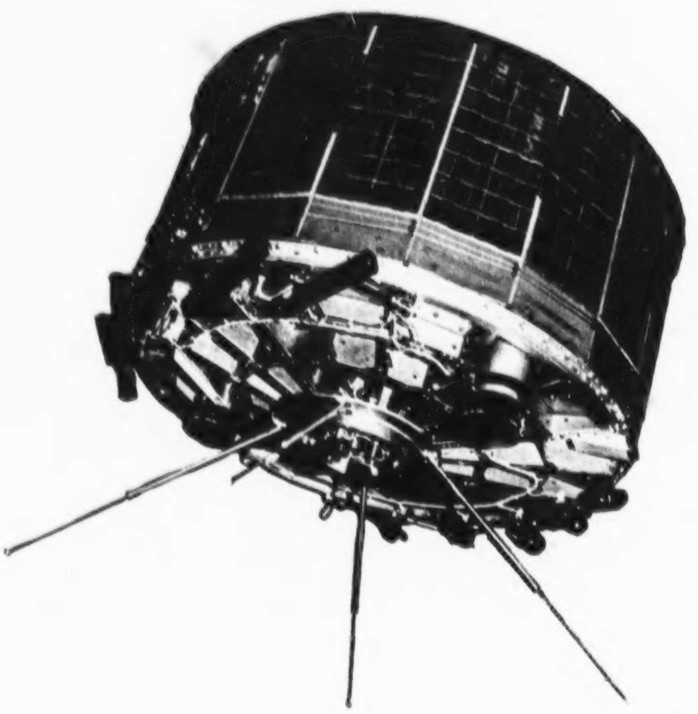
Telstar was developed by the American Telephone and Telegraph Company and launched by NASA. The company reimbursed NASA for expenses of launching, tracking, and acquiring data from the satellite.

Two satellites were launched in the Telstar program. Telstar I was launched July 10, 1962. It made communications history by relaying the first telecast from Europe to the United States on the day of launch. Telstar II was launched May 7, 1963. Both satellites were successful.

EARLY BIRD Early Bird, launched April 6, 1965, is the world's first operational commercial communications satellite. Its owner, the Communications Satellite Corporation, is reimbursing NASA for costs involved in launching, tracking, and monitoring the satellite. Early Bird has been guided by earth stations into a nearly stationary position (relative to earth's surface) over the Atlantic Ocean. From that point, it has been able to furnish communications service (including telecasts) between Europe and North America.

The Communications Satellite Act, which became law on August 31, 1962, called for establishment, in conjunction and cooperation with other nations, of a commercial communications satellite system. The system would be an integral part of an improved global communications network.

TRANSIT AND THE NAVY NAVIGATION SATELLITE SYSTEM Transit was a Department of Defense experimental navigation satellite program designed to lead to a world-wide operational navigation-satellite system for American military ships. The operational system, consisting of four



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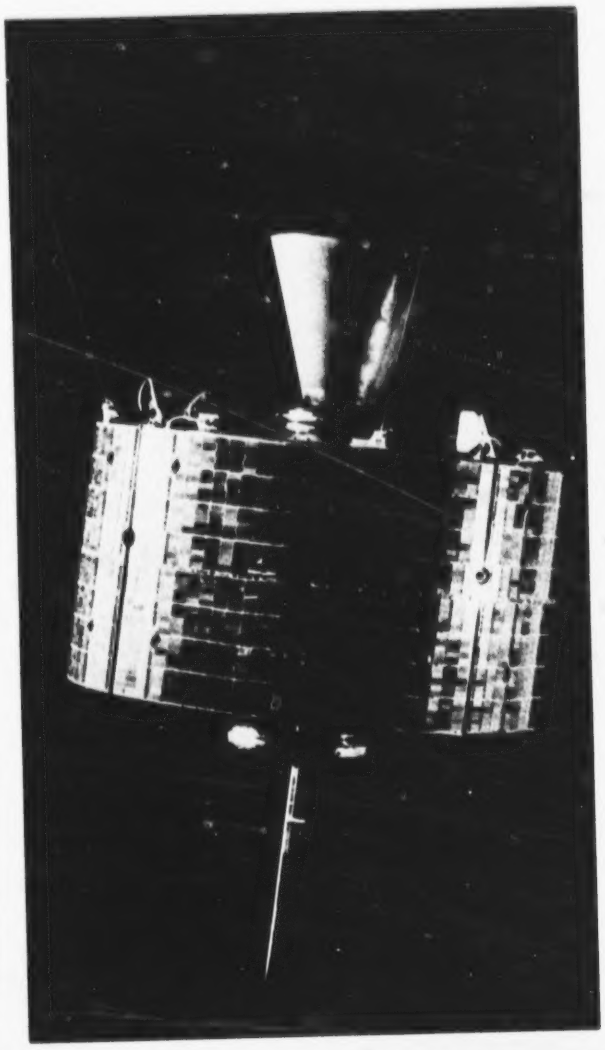

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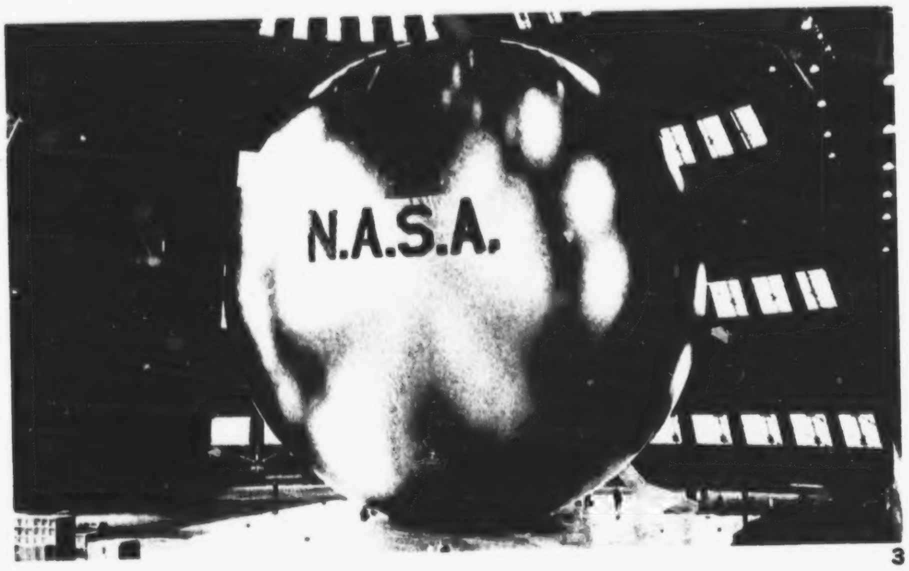

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1. *TIROS weather satellite.*
2. *Syncom communications satellite.*
3. *Echo II communications satellite.*
4. *Relay communications satellite.*
5. *Early Bird communications satellite.*
6. *Telstar communications satellite.*

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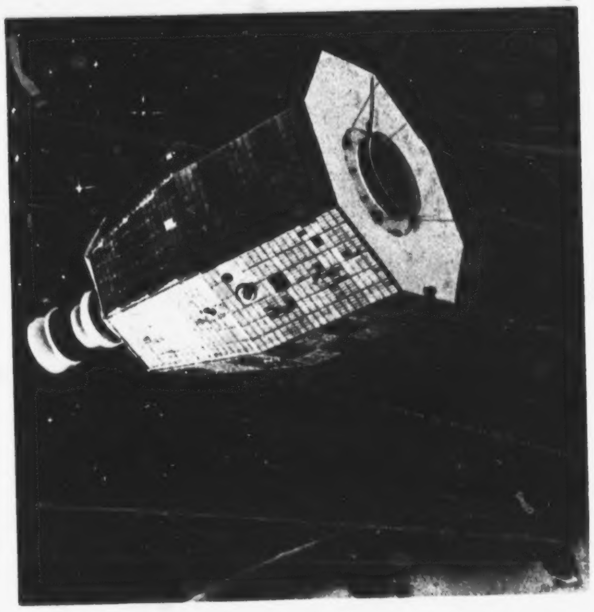

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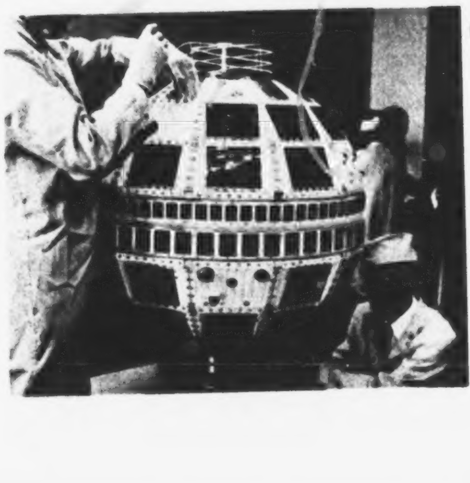

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1. *Automatic Picture Transmission (APT) ground equipment to get weather photographs from meteorological satellites.*

2. *Nimbus infrared night-time photograph of Europe. Italian boot can be seen at bottom; Scandinavian peninsula (Norway and Sweden), at top.*

3. *Hurricane Betsy photographed by TIROS X on September 6, 1965. Note eye of hurricane.*

4. *Nimbus weather satellite.*

5. *Mosaic of TIROS IX weather satellite pictures taken February 13, 1965, provides first complete view of world's weather.*

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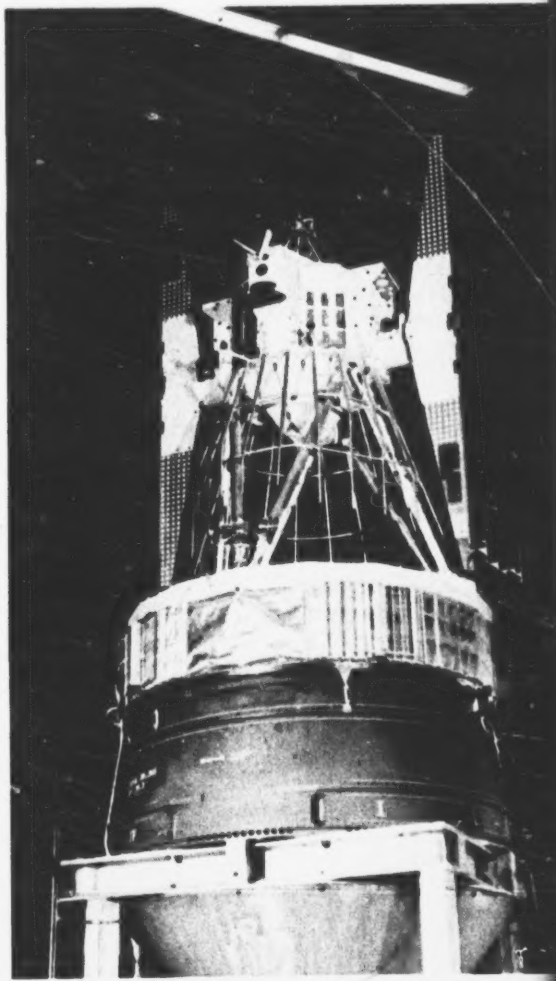

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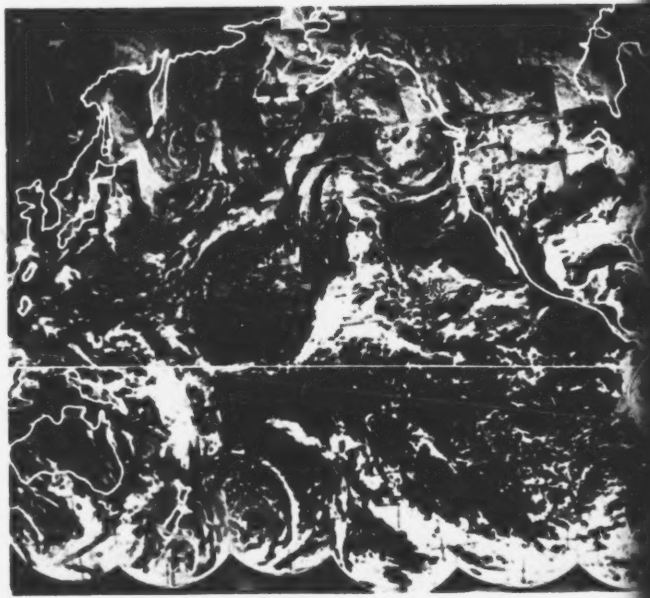

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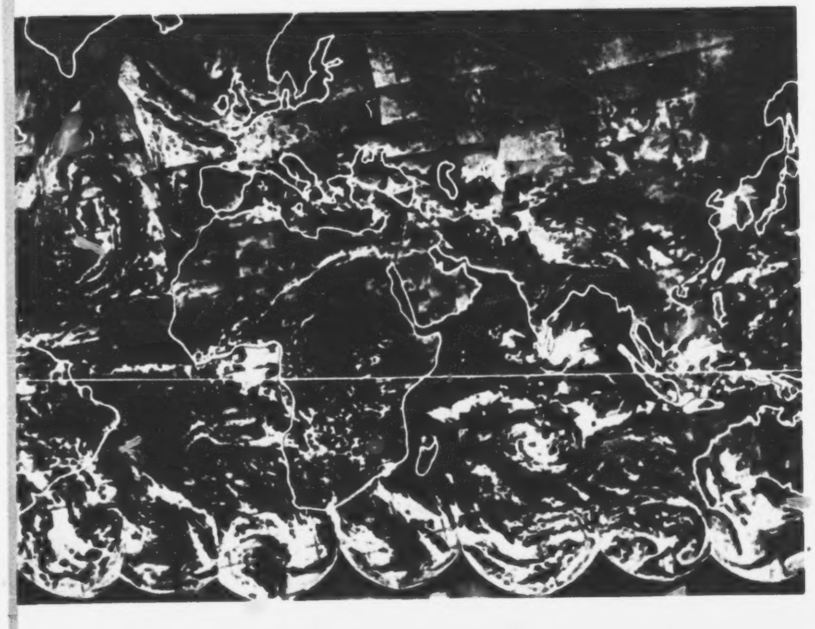
satellites that are properly positioned relative to each other, is intended to provide accurate data for navigational fixes on an average of once every 1¾ hours. The system is designed to allow users to determine their precise position on earth regardless of weather and time of day. The first Transit satellite, Transit I-B, was launched April 13, 1960. Several additional Transits were launched prior to July 1964 when the Department of Defense declared the Navy Navigation Satellite System operational.

NAVIGATION AND AIR TRAFFIC CONTROL SATELLITE NASA is studying a satellite system to aid aircraft and ships in determining their exact locations regardless of weather. The system will also serve to control transoceanic traffic and to facilitate air-sea rescue operations. Plans call for the equipment on the satellite, ships, and airplanes to be simple and durable. Moreover, the ship and aircraft equipment will be relatively easy to operate and maintain. As currently envisioned, the system would operate as follows: The ship or aircraft radios a signal to the satellite which relays it to a ground station. Computers at the ground station, utilizing the satellite as a reference point, calculate the position of the plane or ship and flash this information via the satellite to the ship or aircraft. The operation takes less than a second.



APPLICATIONS TECHNOLOGY SATELLITE The Applications Technology Satellite (ATS) is designed to test in space promising techniques and equipment for use in future meteorological, navigation, and communications satellite systems. The satellite will also carry scientific experiments such as instruments to measure radiation in space. The approximately 700-pound spacecraft is designed to include from 100 to 300 pounds of experimental equipment. Planned orbits are at a 6500-mile altitude and at synchronous (approximately 22,235 mile) altitude.

TIROS Originally a research and development project, TIROS has evolved into an operational weather observation system. TIROS stands for *T*elevision and *I*nfra-*R*ed *O*bservation *S*atellite. The first TIROS satellite was launched on April 1, 1960. Since then, TIROS I and subsequent satellites have proved themselves the most effective storm detection system known. They have provided meteorologists with more than half a million usable cloud-cover pictures, enabling them to track, forecast, and analyze storms. Through TIROS observations, the U.S. Weather Bureau has issued thousands of storm bulletins to countries throughout the world.

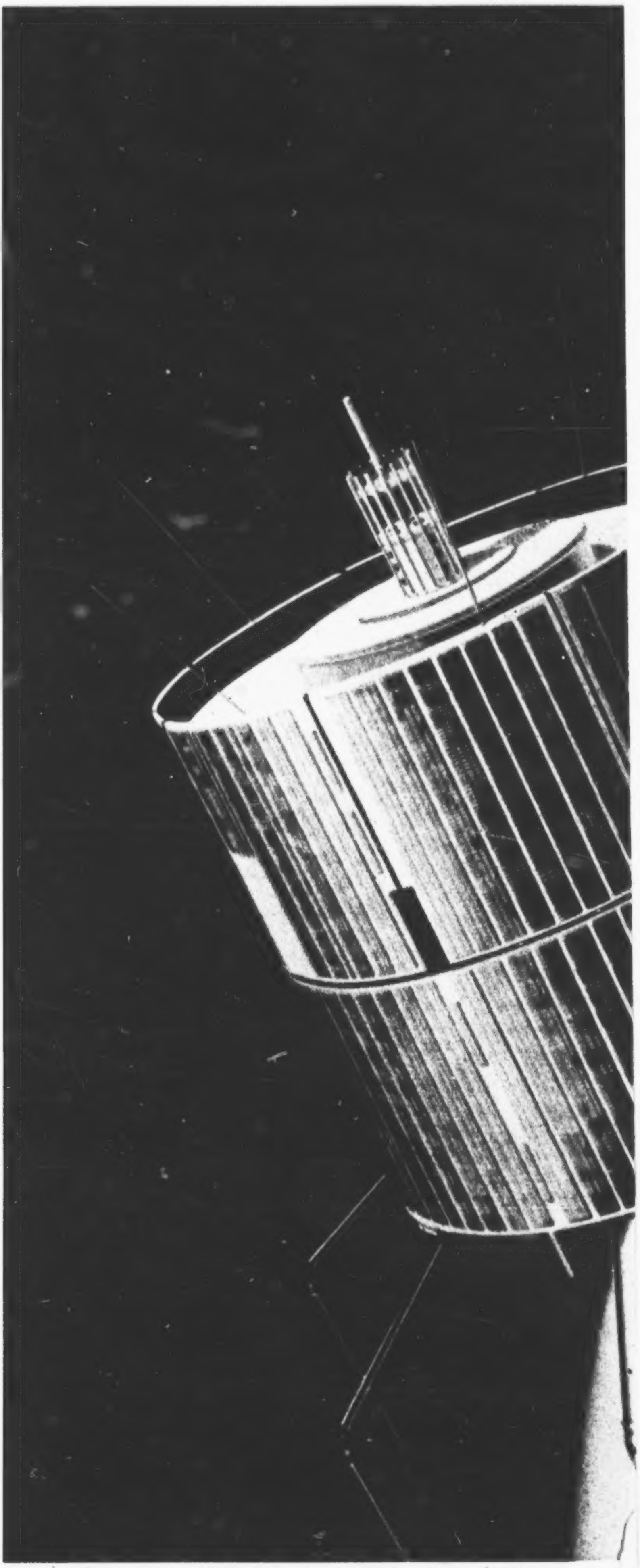
Continued progress has been made in improving the observations made by TIROS and in making these observations available to weather services of other nations. TIROS satellites now provide almost global coverage as compared to the coverage of about 25 percent of the earth's surface at the program's inception. They can provide high quality pictures of earth's cloud cover. Some are equipped with an automatic picture transmission (APT) system that permits receipt of TIROS cloud-cover photographs on the ground with relatively inexpensive ground equipment. Such equipment is now in use in many nations. In addition to contributing significantly to the discovery and tracking of hurricanes and other weather phenomena, TIROS satellites are providing valuable data for meteorological research. Such research may lead to long-range weather forecasts and perhaps greater understanding of how hurricanes and other destructive storms breed and how their development can be curbed. TIROS pictures of the earth are proving useful in geography and geology, in showing the magnitude of river and sea ice, and in furnishing information on snowcover for use in predicting the extent of spring flooding. Other possible uses of TIROS observations are being examined.

NIMBUS Advanced equipment intended for use in future operational weather satellites is tested in Nimbus, a research and development project. Nimbus I was launched August 28, 1964. Equipped with advanced television cameras and with a high resolution infrared observation system, the satellite was the first to provide both day and night pictures of the earth. The cameras provided the day pictures; the infrared equipment, the night pictures.

The thousands of day and night pictures taken by Nimbus I have contributed significantly not only to study and tracking of hurricanes and other weather phenomena but also to geology, geography, oceanography, and other earth sciences.

Nimbus II, launched May 15, 1966, contained equipment not only for providing day and night pictures of the earth and its clouds but also for measuring the earth's heat balance. Heat balance refers to how much of the sun's radiation the earth absorbs and how much it reflects back into the atmosphere. The Nimbus II experiment represents the first time such information was obtained on a global basis. Study of heat balance data may increase understanding of how storms are born, develop, and die.

TOS and ESSA NASA's research and development work with meteorological satellites has led to the world's first operational weather satellite system, called TOS (for *T*IROS *O*perational *S*atellite). The TOS system is furnishing weathermen daily with pictures of the weather over nearly the whole earth. TOS is financed, managed, and operated by the Weather Bureau, a part of the Environmental Science Services Administration of the United States Department of Commerce. A TOS satellite is named ESSA for *E*nvironmental *S*urvey *Sa*tellite. ESSA I was launched by NASA on February 3, 1966; ESSA II, on February 28, 1966; and ESSA III, on October 2, 1966.



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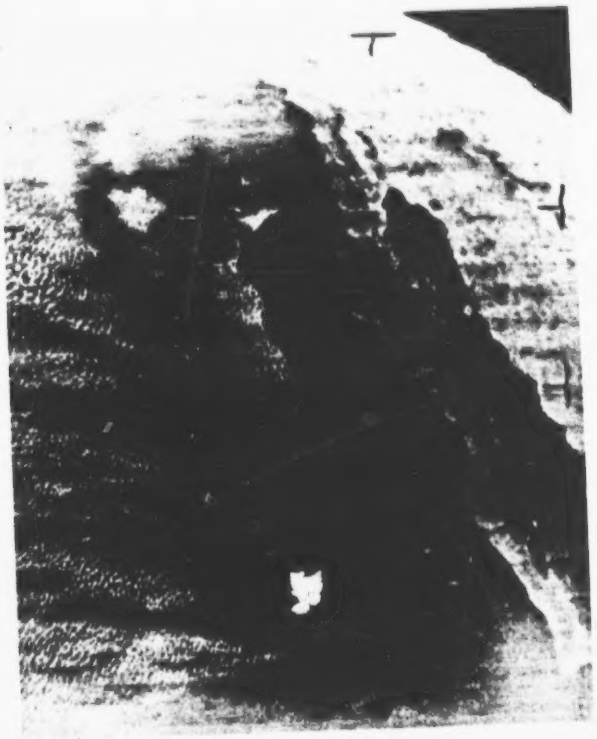

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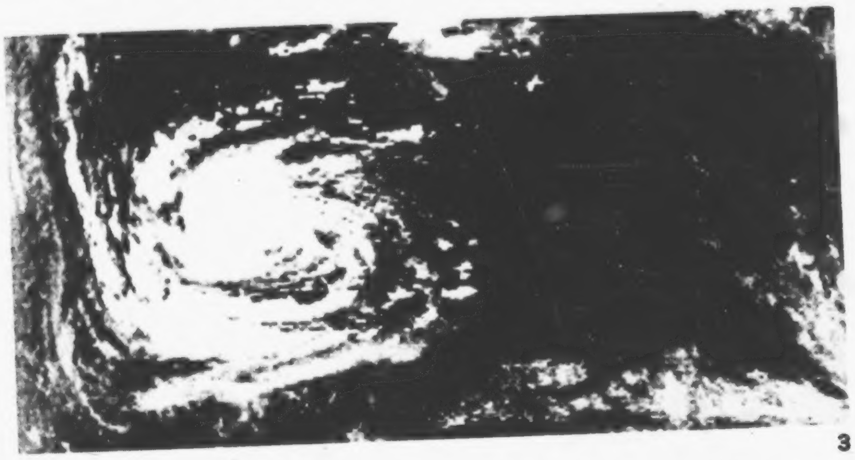

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1. *One of three major types of Applications Technology Satellites.*
2. *TIROS VIII APT picture of Lower California (Baja California).*
3. *Nimbus infrared night-time picture of Hurricane Ethel on September 10, 1965.*

Unmanned Lunar & Interplanetary Spacecraft

VII

Short of manned landings, unmanned instrumented spacecraft are the best means of obtaining information about other planets and the moon. Already, the bits of scientific data and the pictures acquired by means of NASA's spacecraft have tremendously increased man's knowledge of the Moon, Venus, and Mars. This increased knowledge is contributing to preparations for eventual manned landings. ¶ Unmanned lunar and interplanetary spacecraft of the United States are described in this chapter. These include Ranger, Lunar Orbiter, and Surveyor which are designed to provide information about the moon. Also described are Mariner, Voyager, and Pioneer which are intended to provide information about interplanetary space, including the Sun, Mars, Venus, and the environment of space, itself.

LUNAR ORBITER Lunar Orbiter I, launched August 10, 1966, was the first of a series of a series of spacecraft designed to orbit the moon and return close-up pictures and other information about earth's only natural satellite. Lunar Orbiter II launched November 6, 1966, continued studies of the moon. The photographs and other information returned to earth by Lunar Orbiter spacecraft are contributing to eventual manned landings on the moon and adding significantly to knowledge.

RANGER NASA's Project Ranger made possible the greatest single advance in lunar knowledge since Galileo first studied the moon through a telescope more than three centuries ago. In the program, Ranger spacecraft telecast to earth 17,255 close-ups of the moon. Features as small as 10 inches across on the lunar surface were made visible to man for the first time. By way of comparison, man can discern lunar objects no smaller than a half mile in size when he looks through his best telescopes on earth.

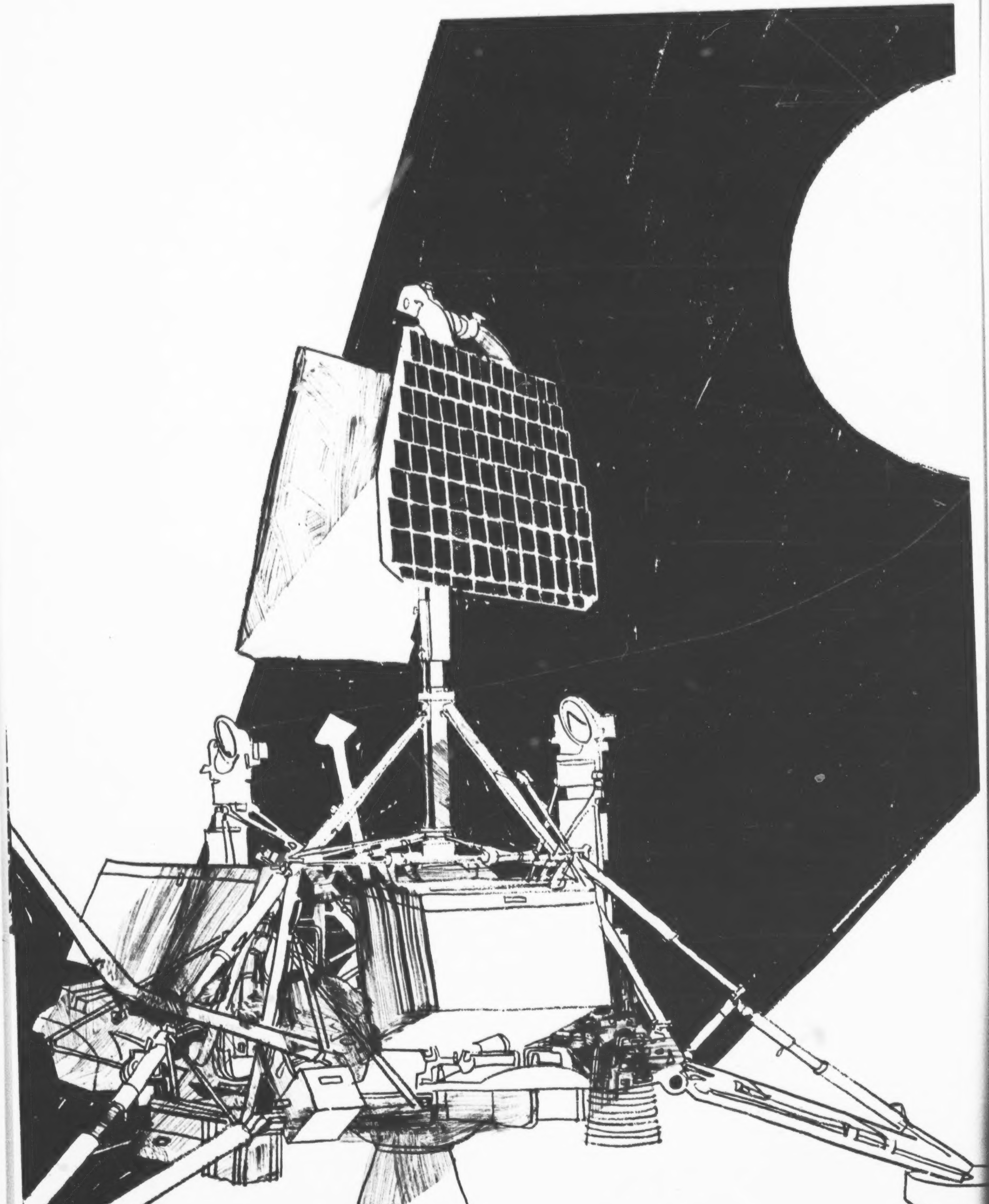


TABLE III. SOME FACTS ON RANGER LAUNCHES

CRAFT	LAUNCH DATE	GOAL(S)	RESULTS
RANGER I	August 23, 1961	Looping orbit stretching 500,000 miles from earth; equipment test; acquisition of space environmental data.	Low-altitude (approximately 100-mile) orbit.
RANGER II	November 18, 1961	Same as Ranger I.	Same as Ranger I.
RANGER III	January 26, 1962	Send pictures of the moon and other scientific information.	Missed moon and soared into solar orbit.
RANGER IV	April 23, 1962	Same as Ranger III.	Curved around moon and struck side away from earth. Sent no information.
RANGER V	October 18, 1962	Same as Ranger III.	Missed moon and soared into solar orbit.
RANGER VI	January 30, 1964	Send close-up pictures of the moon.	Crashed precisely into the lunar Sea of Tranquillity without sending pictures.
RANGER VII	July 28, 1964	Send close-ups of lunar Sea of Clouds.	Objective achieved; 4304 pictures transmitted and received on earth.
RANGER VIII	February 17, 1965	Send close-ups of lunar Sea of Tranquillity and highland area west of the sea.	Objective achieved; 7137 pictures returned.
RANGER IX	March 21, 1965	Send close-ups of Crater Alphonsus and vicinity.	Objective achieved; 5814 pictures returned.

The Ranger close-ups added to and in some ways altered man's knowledge about the moon. It is anticipated that they will be closely studied by lunar scientists throughout the world for many years to come. Samples of the Ranger moon photographs, some discussion of what the photographs indicate, and other information about the moon are presented in Chapter III.

Rangers VII through IX, the last of the Ranger series, began telecasting pictures when they were about 20 minutes away from the moon and continued to telecast until crashing onto the surface. The Rangers with the television packages were about 5 feet in diameter at their hexagonal base and approximately 8¼ feet long. Cruising in space with appendages extended, Ranger spanned 15 feet across its wing-like solar panels and measured 10¼ feet to the far edge of its dish-shaped antenna. (The solar panels converted sunlight to electricity for powering the spacecraft.) Ranger weighed about 805 pounds. A summary of and some facts on Ranger launches are presented above.

SURVEYOR Surveyor is designed to decelerate from the lunar approach velocity of 6,000 miles per hour, or 9,000 feet per second, to a touchdown speed of about 3½ miles per hour.

The first Surveyors are designed as engineering test spacecraft intended primarily to test soft landing techniques. Each of these spacecraft carry a single scanning television camera. Their legs are instrumented to return information on the hardness of the moon's surface.

Surveyor I soft-landed on the moon June 2, 1966. It telecast thousands of close-ups of the lunar surface surrounding it.

MARINER Mariner is the designation of a series of spacecraft designed to fly in the vicinities of and send information about Venus and Mars. Of the four craft launched, two successfully accomplished their difficult missions. They significantly advanced knowledge about Venus and Mars (see Chapter III, The Solar System) and contributed important information about interplanetary space. On December 14, 1962, Mariner II flew as close as 21,648 miles to Venus, giving man his first relatively close-up study of the cloud-covered planet. Contact with Mariner II, now in solar orbit, was lost on January 3, 1963. At the time, the craft was 53.9 million miles from earth.

On July 14, 1965, Mariner IV snapped the first close-up pictures ever taken of another planet as it sped by Mars at distances ranging from 10,500 to 7400 miles. (It came as close as 6118 miles to Mars but took no pictures then because it was on Mars night side.)

NASA received interplanetary data from Mariner IV until October 1, 1965, when the craft was about 191 million miles from earth. Periodic attempts to track the spacecraft have been carried out as Mariner IV orbits the sun. Mariner IV has far exceeded design expectations and established new records in space communication.

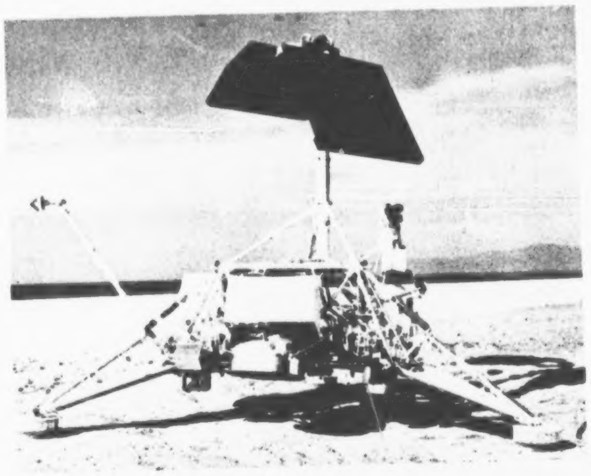
Mariner IV confirmed many of the original findings of Mariner II about interplanetary space. Among information provided about interplanetary space by Mariners II and IV were the following:

- The solar wind, consisting of very hot electrified gases, rushes constantly from the sun's turbulent surface.
- The density, velocity, and temperature of the wind fluctuate with the solar cycle.
- Solar flares increase the magnitude of the wind.
- The wind influences the amount of cosmic radiation in interplanetary space.
- Interplanetary magnetic fields vary directly with the magnitude of the solar wind. The wind modifies and distorts both the interplanetary and earth's magnetic fields. The wind creates interplanetary fields.
- Micrometeoroids (tiny bits of matter in space) are far less numerous in interplanetary space than around earth. However, no comparable concentrations around Venus and Mars were reported by Mariners II and IV.
- Reliable radio communication is possible between earth and spacecraft over interplanetary distances.

Tracking data from Mariners II and IV contributed to refinements of important measurements such as: the Astronomical Unit (AU) which is the distance from the earth to the sun; of the orbits of Mars and Venus; and of the masses of the Moon, Mars and Venus.

More information was acquired on the interaction

1. *Surveyor.*
2. *Ranger hurtles toward moon (artist's conception).*
3. *Model of Lunar Orbiter.*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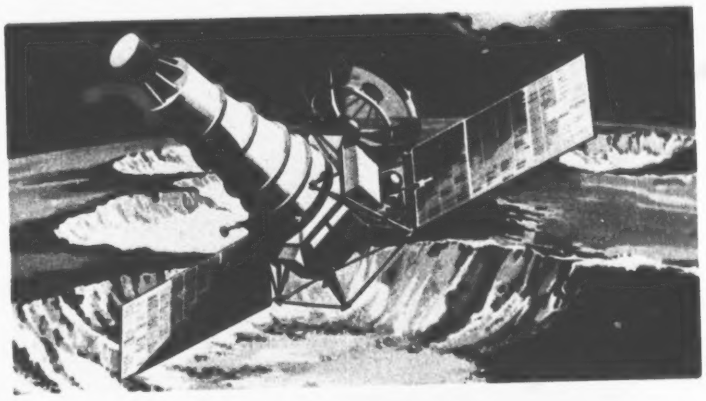
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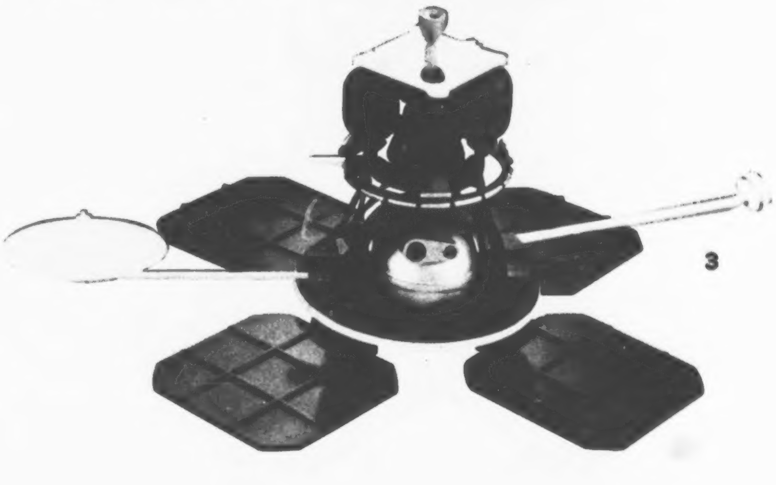
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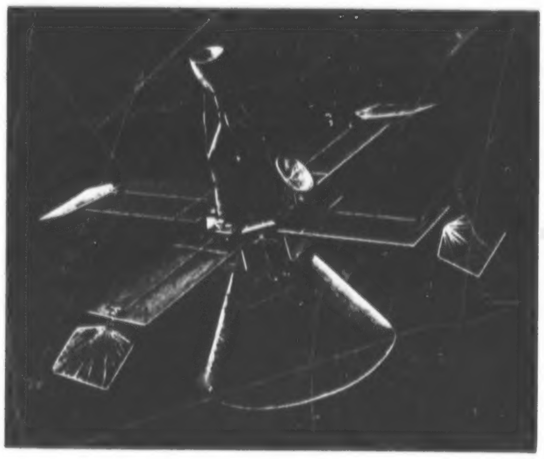

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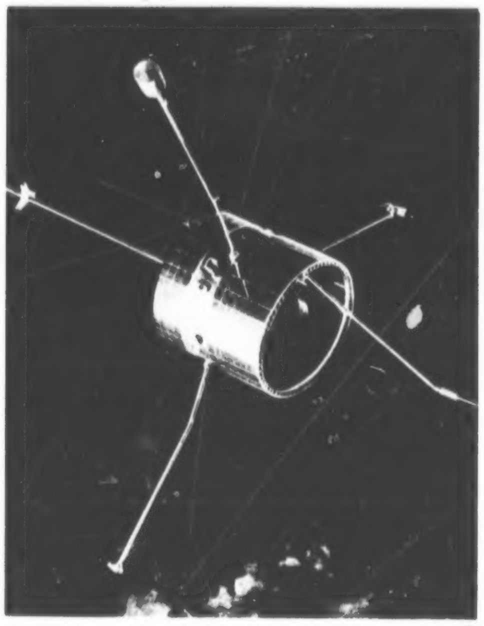

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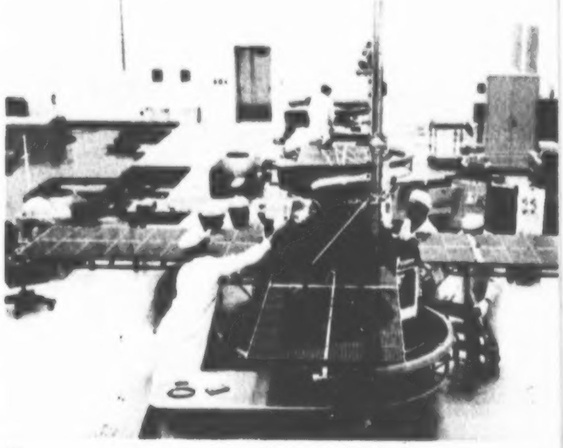

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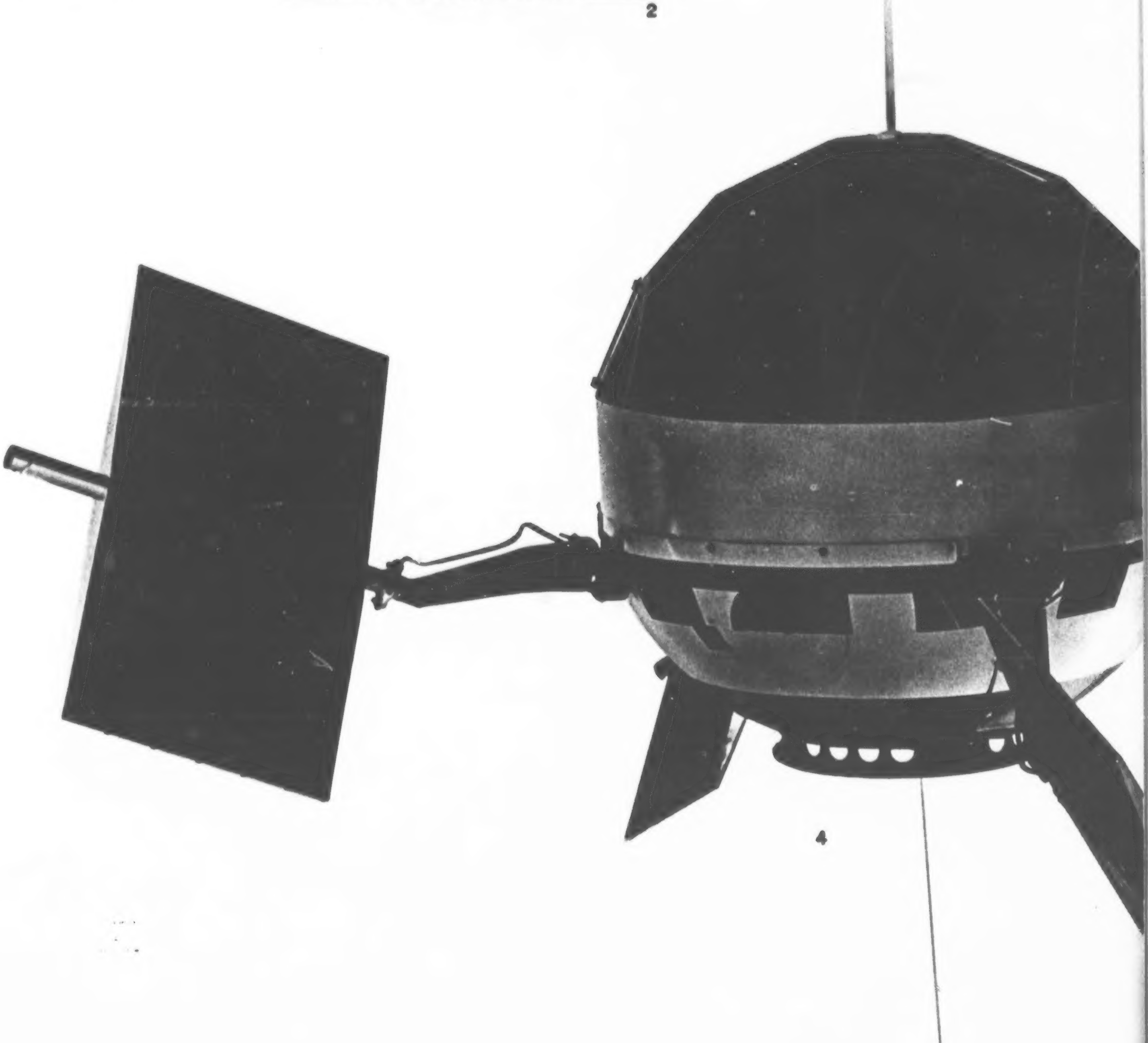
1. *Artist's concept of Voyager spacecraft.*
2. *Pioneer VI, first of a new series of Pioneer spacecraft.*
3. *Mariner IV is prepared for flight.*
4. *Pioneer V.*



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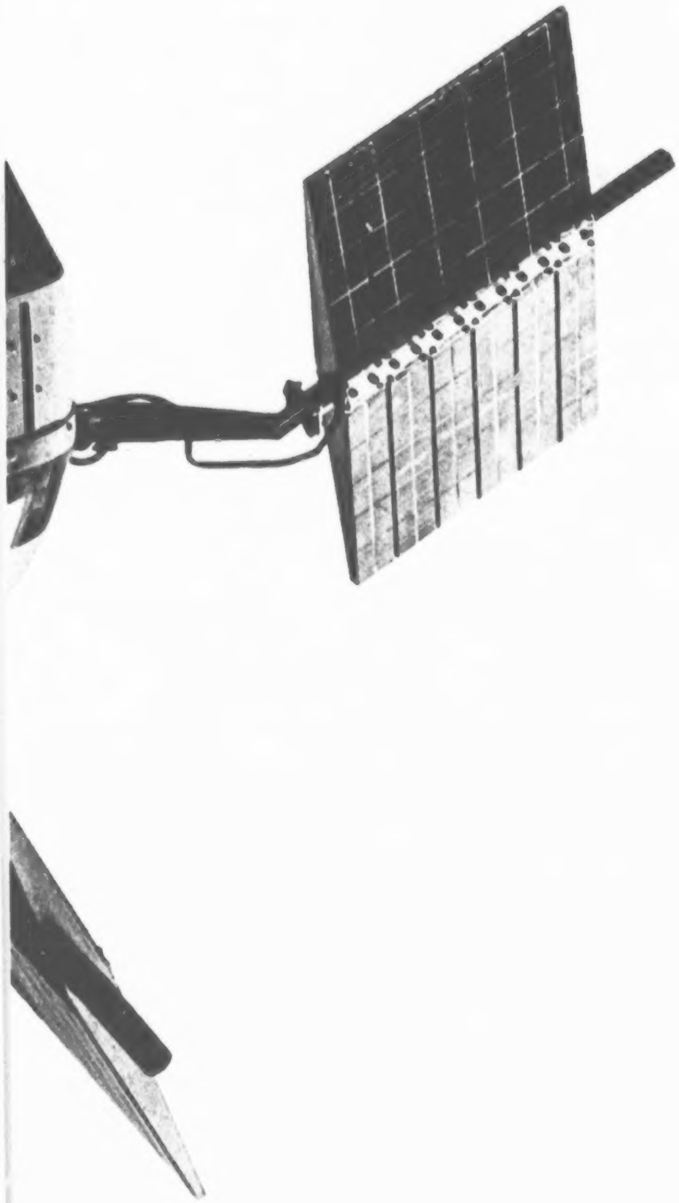
of particle radiation (made up of particles of atoms, such as electrons and protons) with magnetic fields. In addition, experience was gained in tracking, guiding, monitoring, and acquiring useful information from spacecraft as they speed hundreds of million of miles through space.

The vast extension of scientific knowledge about interplanetary space already provided by the Mariner spacecraft will help blaze the way for eventual landing of instruments and later men on Mars, Venus, and the farther planets of the solar system.



Three additional Mariner flights are planned. In 1967, a modified Mariner IV type spacecraft will be launched toward Venus. Its purpose will be to provide more information about the composition and density of the thick clouds surrounding the planet. In 1969, plans call for launch of two larger Mariners to Mars. They will be designed to make more complex measurements than Mariner IV. In all five missions, the craft will fly by rather than land on the planets.

VOYAGER NASA plans a series of advanced spacecraft called Voyagers to study Mars from orbits around the Red Planet and from instrumented packages landed on its surface. Voyager flights to Mars are scheduled for the 1970's.

PIONEER Pioneer was the designation of NASA's first series of long-distance spacecraft. Of these, the most notable was Pioneer V, launched March 11, 1960. Radio communication with Pioneer V was maintained until June 26, 1960, when the craft was about 22.5 million miles from earth, a record for the period. The spacecraft still is in orbit around the sun.

NASA opened a new series of Pioneer experiments with the launch of Pioneer VI on December 16, 1965. The series is designed to monitor on a continuing basis phenomena of interplanetary space such as radiation, magnetic fields, and the solar wind.

Some Pioneers are investigating space between earth and Venus; others, between earth and Mars. The knowledge gained is expected to advance scientific understanding and contribute to planning for manned interplanetary space flights.

Radio contact with Mariner IV was made when it was 216 million miles away from earth. No attempt was made to acquire data because of the extreme distance involved.

The contact, one of a series to see if Mariner IV is still operating, was made on January 4, 1966. From this date, Mariner IV and earth will draw closer together. In 1967, Mariner IV is expected to come within 30 million miles of earth. NASA then will attempt to get more information about space from Mariner if the spacecraft is still functioning.

Manned Space Flight Programs

VIII

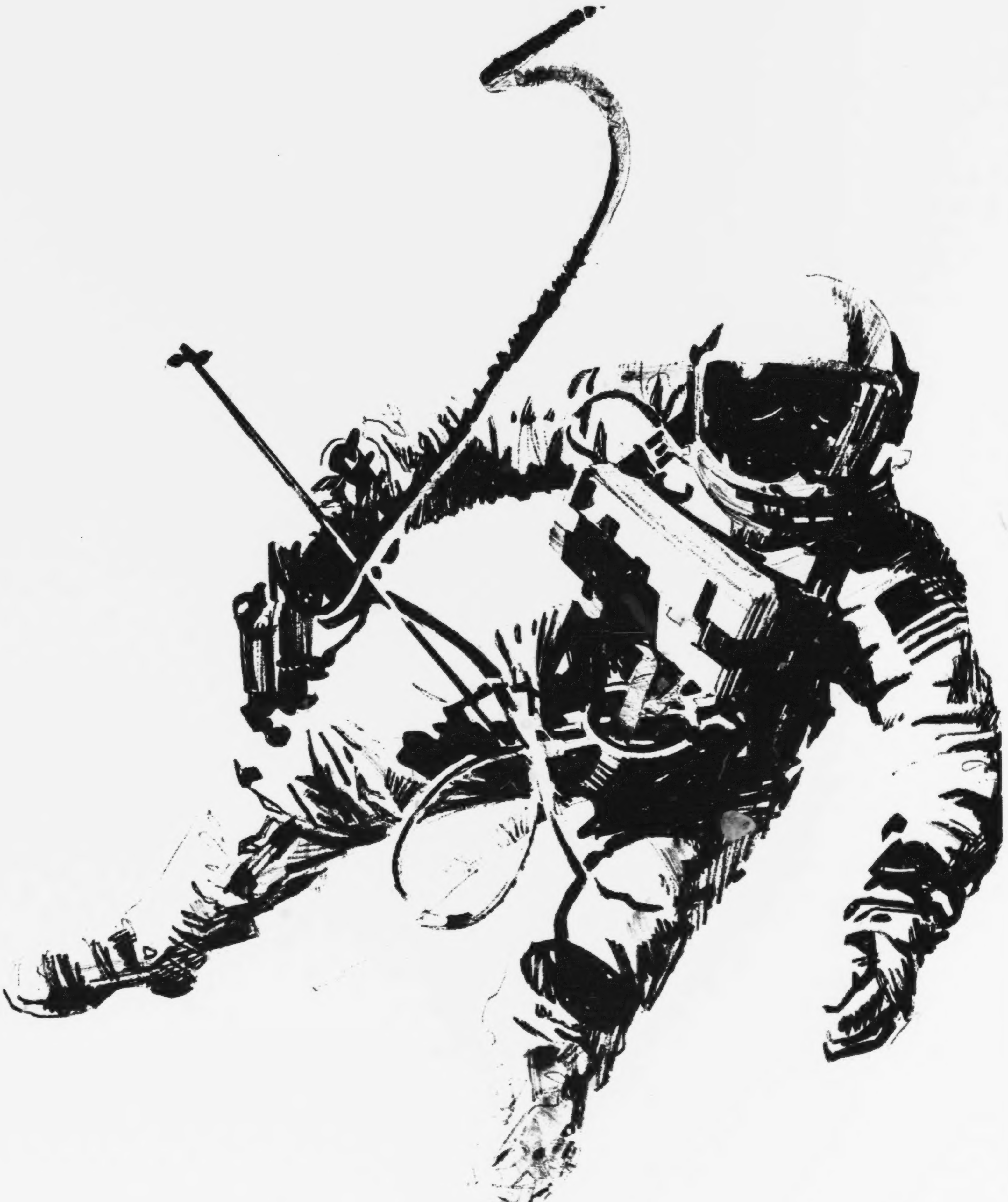
Since almost the dawn of civilization, man has been fascinated by the thought of space travel. America's manned space flight programs are turning these dreams into reality. ¶ The Nation's manned space flight experiments have demonstrated that the planned trip to the moon, the assembly and repair of craft in space, and the maintenance and operation of manned space stations are within the range of today's technology. They have shown that the capabilities for manned trips to earth's planetary neighbors, Mars and Venus, are within reach. Even longer steps across the threshold of the unknown may be accomplished before the end of this century. ¶ A number of projects make up America's manned space flight program. They are described in this chapter.

PROJECT MERCURY Project Mercury placed the first Americans into space. The pioneering project was organized on October 5, 1958, to orbit a manned spacecraft, investigate man's reaction to, and abilities in, space flight, and recover both man and spacecraft.

Project Mercury experiments demonstrated that the high-gravity forces of launch and of atmosphere entry and weightlessness in orbit for as much as 34 hours do not impair main's ability to control a spacecraft. It proved that man not only augments the reliability of spacecraft controls but also can conduct scientific observations and experiments that expand and clarify information from instruments.

Moreover, man can respond to and record the unexpected, a faculty beyond the capability of a machine which can be programmed only to deal with what we know or expect. In addition, Mercury has confirmed that man can consume food and beverages while weightless, if these are in suitable containers such as squeeze tubes. Finally, Mercury has laid a sound foundation for the technology of manned space flight.

The first American rocketed into space was Astronaut Alan B. Shepard, Jr., on May 5, 1961. A Redstone rocket launched him from Cape Canaveral (now



Kennedy), Florida. His Mercury spacecraft was launched to an altitude of about 115 miles and reached a top speed of approximately 5000 miles per hour during a suborbital flight of slightly more than 15 minutes. He landed in the Atlantic Ocean about 302 miles from the Cape.

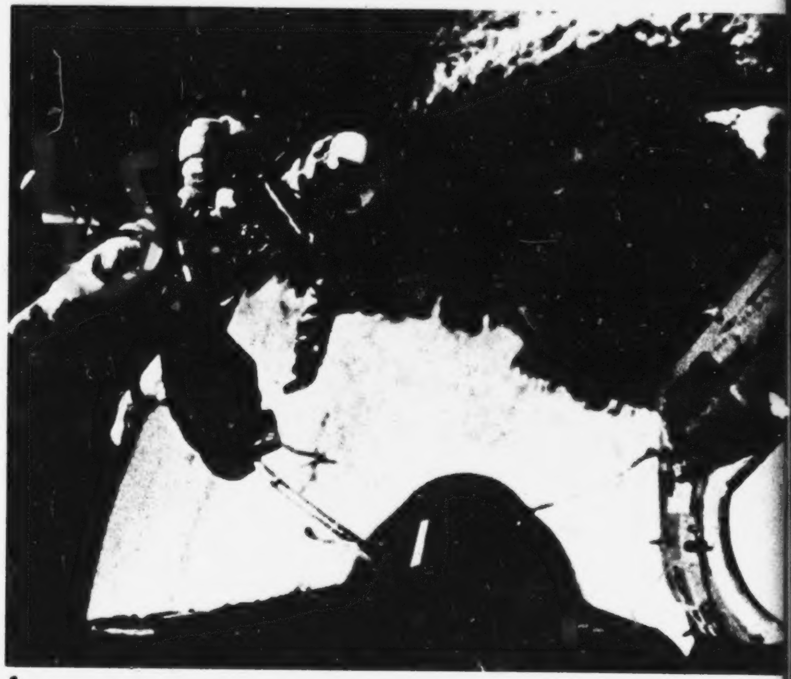
The first American to orbit the earth was Astronaut John H. Glenn, Jr. Launched by an Atlas booster, his Mercury spacecraft circled the earth three times on February 20, 1962. During his orbital flight, his altitude ranged from 86 to 141 miles. His speed was about 17,500 miles per hour.

Some features of these and other Mercury manned flights are noted in the following table.

Table IV
HIGHLIGHTS OF MANNED MERCURY FLIGHTS

Astronaut	Date	Flight Time*	Orbits	Spacecraft Name
Alan B. Shepard, Jr.	5/5/61	00:15:22	Suborbital	Freedom 7
Virgil I. Grissom	7/21/61	00:15:37	Suborbital	Liberty Bell 7
John H. Glenn, Jr.	2/20/62	04:55:23	3	Friendship 7
M. Scott Carpenter	5/24/62	04:56:05	3	Aurora 7
Walter M. Schirra, Jr.	10/3/62	09:13:11	6	Sigma 7
L. Gordon Cooper, Jr.	5/15, 16/63	34:19:49	22	Faith 7
Totals		53:55:27	34	

* Hours:Minutes:Seconds.



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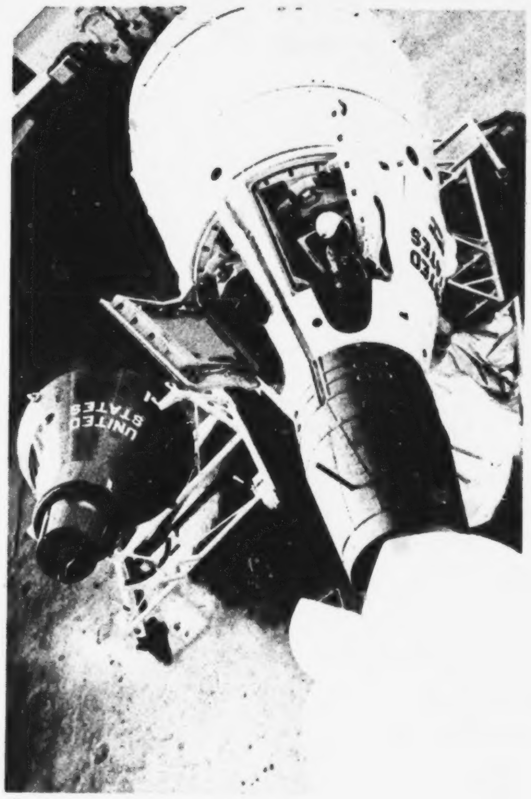

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Astronaut Cooper's flight of 34 hours, 19 minutes, and 49 seconds, was the longest of the Mercury missions. Following his journey, America's manned space flight program moved beyond Mercury to Project Gemini.

The aggregate flight time for suborbital and orbital Mercury manned flights was 53 hours, 55 minutes, and 27 seconds. Plans call for the astronauts to practice for about 2000 hours in orbit around the earth before the first three-man crew embarks in the Apollo spacecraft for the moon. Descriptions of the Gemini and Apollo projects follow.

PROJECT GEMINI Project Gemini has markedly extended the technology and experience gained through Project Mercury and vastly increased knowledge about space, earth, and man. The last of the Gemini missions was Gemini XII completed on November 15, 1966. In achieving all of its major objectives, the Gemini project has demonstrated that man can:

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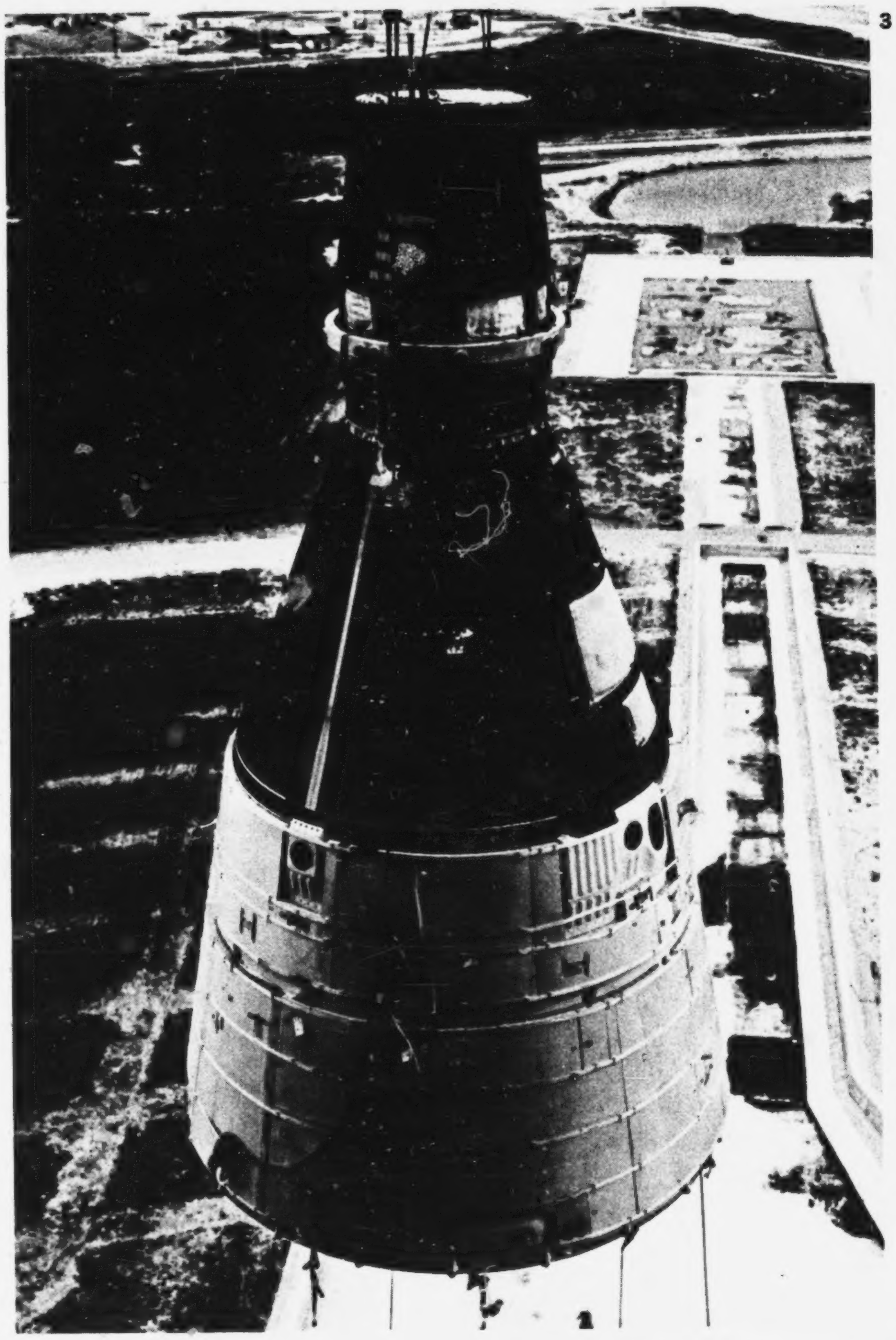

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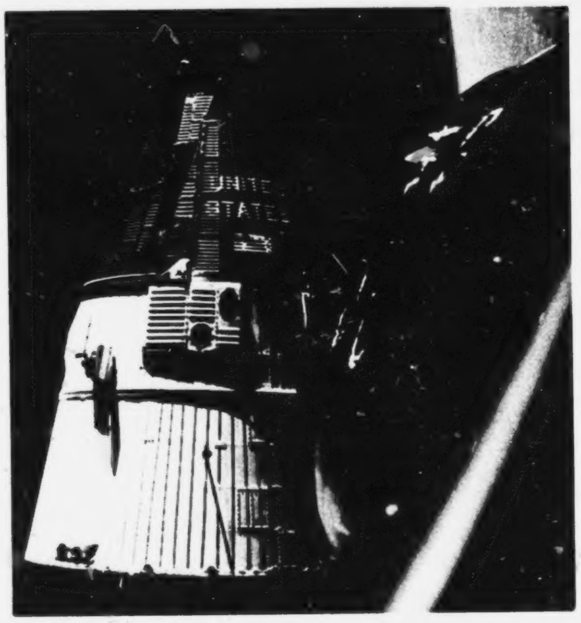

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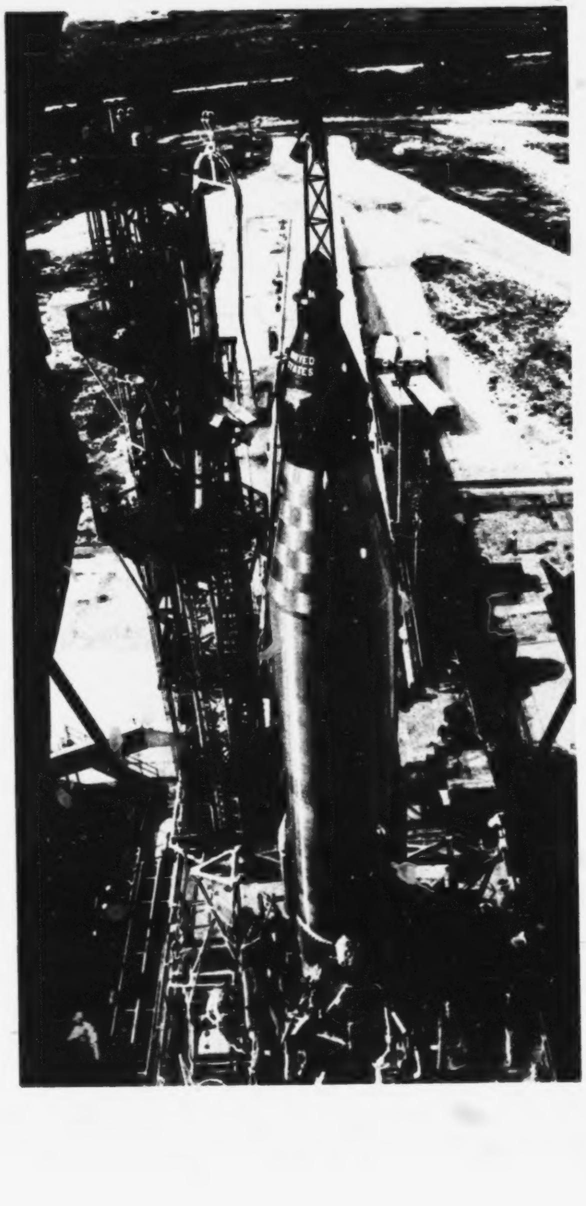


1. *Astronaut Edward H. White II floats in space outside of Gemini 4 on June 3, 1965.*

2. *Mercury and Gemini spacecraft. In front of Gemini is mock-up of Agena rocket docking collar. Gemini's nose enters this slot to link up in orbit with an Agena rocket.*

3. *Gemini is raised for mounting on the top of its Titan II launch vehicle.*

4. *Gemini 7 in space, as photographed from Gemini 6 (foreground) on December 15, 1965.*

5. *Mercury spacecraft atop its modified Atlas launch vehicle.*

- Maneuver his craft in space.
- Leave his craft, survive, and do useful work in space if he is properly clothed and equipped.
- Rendezvous (find and come near) and dock (link up) his craft with another vehicle in space.
- Function effectively during prolonged space flight of at least two weeks and return to earth in good physical condition.
- Control his spacecraft during its descent from orbit and land it within a selected area on earth.

Thus, in Gemini, man has developed and perfected much of the technology and skills that are crucial to the mastery of space. But Gemini has done even more. Experiments conducted as part of Gemini flight missions have provided scientific, technical, and engineering data that add up to a tremendous increase in overall knowledge.

Photographs of earth and its cloud cover taken from orbiting Gemini craft, for example, are providing a wealth of information for oceanographers, meteorologists, and geographers. Study of data on the astronauts, taken before, during, and after Gemini flights is advancing medical knowledge on how the human body functions.

Table V

MANNED GEMINI FLIGHTS

Spacecraft	Pilots	Date(s)	Flight Time*
Gemini III	Grissom-Young	Mar. 23, '65	04 :53 :00
Gemini IV	McDivitt-White	June 3–7, '65	97 :56 :11
Gemini V	Cooper-Conrad	Aug. 21–29, '65	190 :56 :01
Gemini VII	Borman-Lovell	Dec. 4–18, '65	330 :35 :13
Gemini VI	Schirra-Stafford	Dec. 15–16, '65	25 :51 :24
Gemini VIII	Armstrong-Scott	Mar. 16, '66	10 :42 :06
Gemini IX	Stafford-Cernan	June 3–6, '66	72 :20 :56
Gemini X	Young-Collins	July 18–21, '66	70 :46 :45
Gemini XI	Conrad-Gordon	Sept. 12–15, '66	71 :17 :08
Gemini XII	Lovell-Aldrin	Nov. 11–15, '66	94 :34 :30

*Hours :Minutes :Seconds

Spacecraft Resembles Mercury / Experience in developing the Mercury spacecraft and in Mercury flights has contributed to refinements in the Gemini spacecraft. As a result, the two-man Gemini spacecraft externally resembles the one-man Mercury craft and employs the same kind of system for protection against the intense heat generated during entry into the atmosphere.

Gemini is 10 feet wide at its broad end, is 18 feet 5 inches long, and weighs more than 7000 pounds. For comparison, Mercury is 6 feet in diameter at its broad base, 9½ feet long, and weighs about 3000 pounds. Gemini has about 50 percent more cabin space than Mercury.

Of greater importance than size differences are Gemini's more advanced systems. Among these are a radar and computer system for use in orbital rendezvous and in landing at a selected location on earth; an orbit attitude and maneuvering system (OAMS) which enables Gemini to change its orientation and orbit; fuel cells to convert hydrogen and oxygen into electricity for powering the craft; two windows instead of one window as in Mercury; and arrangement of many systems in readily accessible compartments to facilitate maintenance, check-out, and, if necessary, replacement of faulty parts. Gemini's ejection seats, for use in emergencies during launch and landing, operate like those in high performance military aircraft.

Consists Structurally of Two Sections or Modules/ The Gemini spacecraft is structurally divided into the re-entry module and the adapter module. The re-entry module is 11 feet long and has a maximum width of 7½ feet. It is divided into: (1) rendezvous and recovery section—the small nose-like part—which contains the radar system and the parachute landing system; (2) the re-entry control section which is equipped with gas jets to reorient Gemini as required for controlling its descent to earth; and (3) the cabin section which provides a livable environment for the astronauts, stores astronaut equipment, food and other supplies, and contains the instruments that enable the astronauts to control their flight.

The adapter module is 7½ feet long and has a maximum diameter of 10 feet. Its two parts include: (1) the equipment section containing the OAMS, fuel cells, propellent tanks, and associated electronics; and (2) the retrograde section which houses the rocket system for slowing Gemini down so that it returns from orbit to earth.

The re-entry module is designed to be returned to earth. The adapter equipment section is jettisoned in orbit shortly before the rockets of the adapter retrograde section are employed. The retrograde section is discarded shortly after its rockets have ceased firing.

PROJECT APOLLO Apollo is the biggest and most complex of the manned space flight projects. Its goals: land American explorers on the moon and bring them safely back to earth and establish the technology to meet other National interests in space.

Three-Man Spacecraft Composed of Three Modules/The Apollo spacecraft is made up of three sections or modules:

1. COMMAND MODULE—The command module is designed to accommodate three astronauts in a "shirtsleeve" environment; i.e., the astronauts will be able to work, eat, and sleep in the module without pressure suits. The command module, like the crew compartment of an airliner, has windows, and contains controls and instruments (including a computer) of various kinds to enable the astronauts to pilot their craft. Moreover, since the command module is the only one of the three modules which will return to earth, it is built to survive the tremendous deceleration forces and intense heating caused by entry into the atmosphere at 25,000 miles per hour. This is the speed on return to earth from a lunar mission. In the atmosphere, the Apollo crew will be able to guide the spacecraft to a selected landing area. The command module weighs about 5 tons. It stands 11 feet tall and has a base diameter of about 13 feet.

2. SERVICE MODULE—The service module is equipped with rocket engines and fuel supplies to enable the astronauts to propel their craft into and out of lunar orbit and to change their course in space. It will be jettisoned just before the Apollo enters earth's atmosphere. The service module weighs 24 tons. It is 23 feet long and 13 feet in diameter.

3. LUNAR MODULE—The lunar module (LM) is the space ferry that will take two Apollo astronauts down to the moon, carry them from the moon's surface into lunar orbit, and rendezvous with the Apollo command and service modules in lunar orbit. At launch from earth, the LM weighs about 14½ tons. It is some 20 feet high and has a base diameter of 13 feet. Among the LM's equipment are rockets for slowing down before landing on the moon, rockets for launch from the moon and for maneuvering in orbit, and four spiderlike legs that are extended to support the spacecraft on the moon's surface. The legs and landing rockets are left on the moon. After the two-man crew of the LM returns to the command module, the LM is jettisoned in lunar orbit.

THREE STEPS TO THE MOON The Apollo mission is planned for accomplishment in three steps:

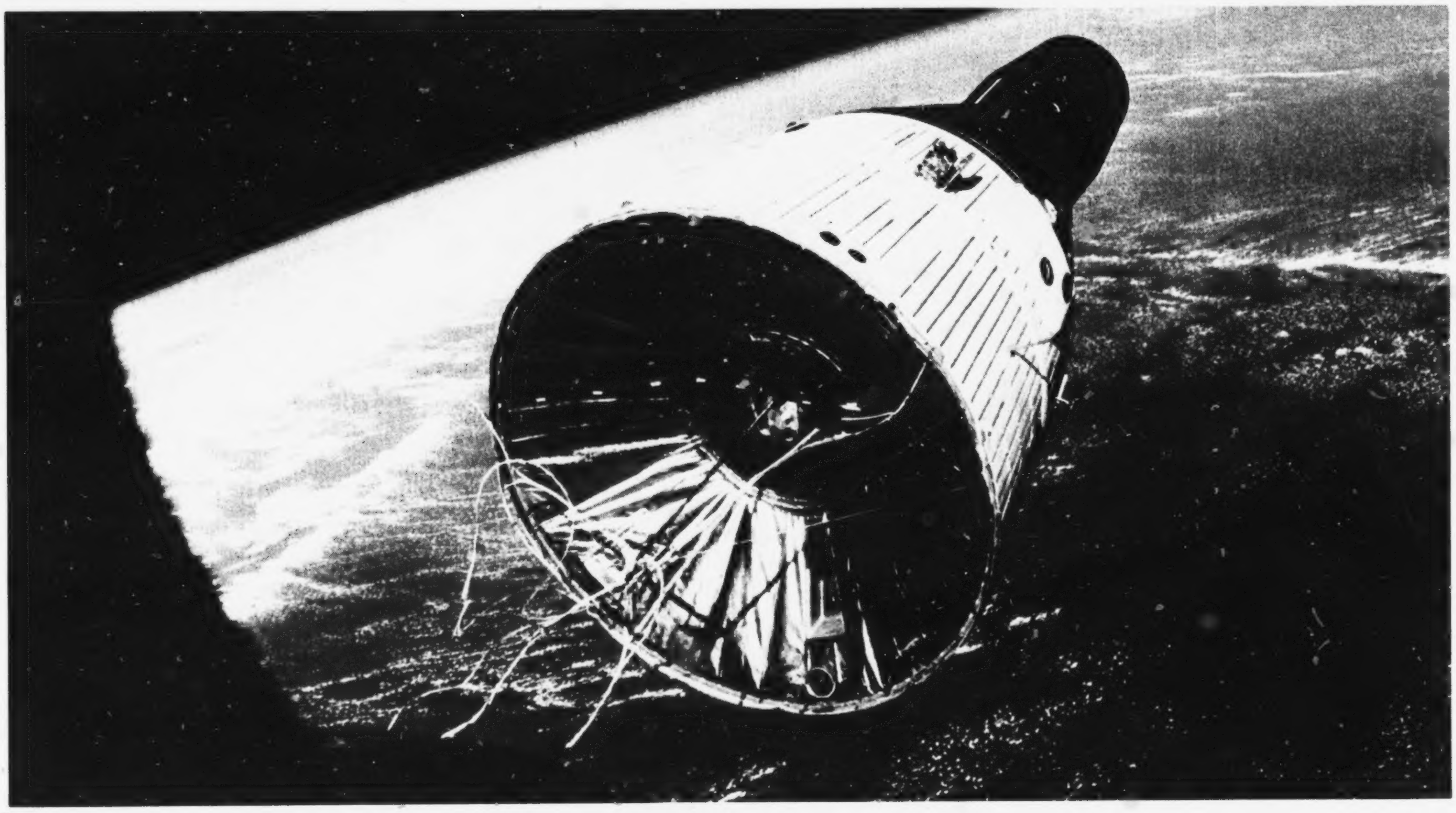
1. The Saturn I launch vehicle placed unmanned boilerplates—engineering and test models—of the Apollo command and service modules into earth orbit. These tests had been completed by July 30, 1965.

2. The successful suborbital test flight of the Uprated Saturn I—Apollo combination on February 26, 1966, marked the opening of the second major step in Apollo. Plans call for a series of orbital tests to advance further the technology and training required for the manned lunar exploration mission. As an example, in one test, Uprated Saturn I will launch a manned Apollo spacecraft into orbit. At launch, the command module with its rocket-powered escape tower is at the top. Under it is the service module and then the LM. While in orbit, the crew will detach the combined command and service modules from the LM, turn the command and service modules around, and connect the command module's nose with that of the LM. Then, two of the three-man crew will enter the LM through a docking hatch, disconnect the LM from the command module, conduct maneuvers, and then rejoin the command module and LM.

3. The Saturn V launch vehicle launches Apollo on its lunar exploration mission. The entire assembly stands about 365 feet tall (more than the length of a football field) and weighs about 6 million pounds at launch. The fuel of the first two Saturn stages and part of the third stage is employed to place Apollo into earth orbit. At the proper position and time for achieving a lunar trajectory, the third stage is refired, accelerating the assembly to almost 25,000 miles per hour.

After burnout of the third stage, the crew disconnects the joined command and service modules (parent craft) and connects the command module nose to nose with the LM.

After reaching the moon's vicinity, Apollo is rotated to a tail forward position and a rocket in the service module is operated to swerve Apollo into a circular orbit about 100 miles above the moon. Two astronauts will enter the LM, detach it, and land it on the moon while the third crew-



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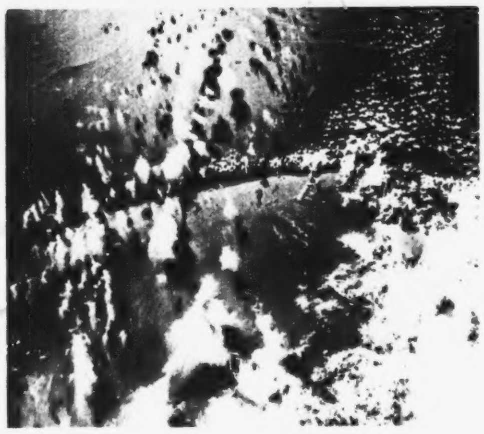

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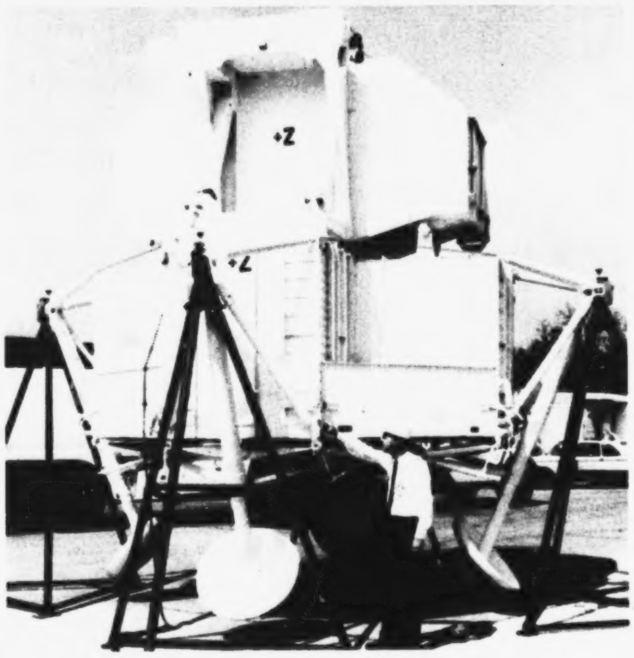
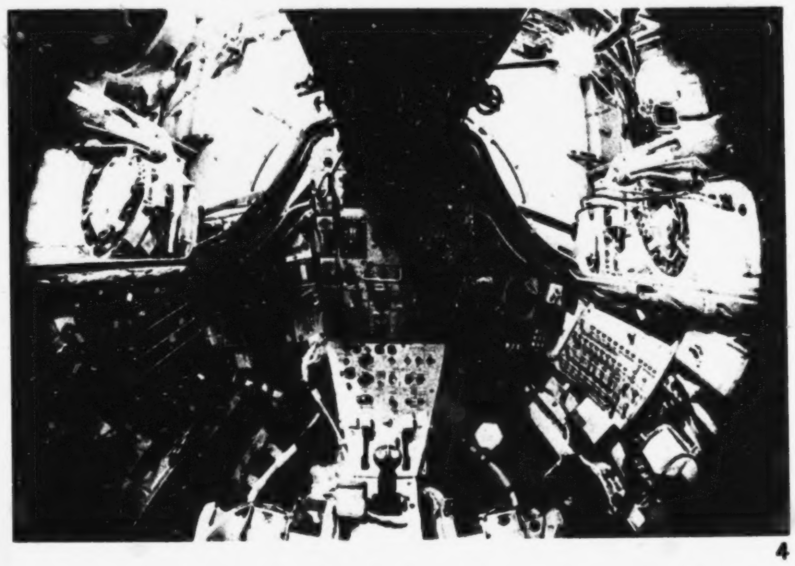


1. *Back view of Gemini 7 taken by camera in Gemini 6 during orbital rendezvous of December 15, 1965.*

2. *The edge of the Grand Bahama Bank, Bahama Islands, in the Atlantic Ocean as photographed from Gemini in orbit. The light portion of the water is shallow. The dark area is deep water.*

3. *Test model of Apollo Lunar Module. Astronauts will first land on the moon in a craft like this.*



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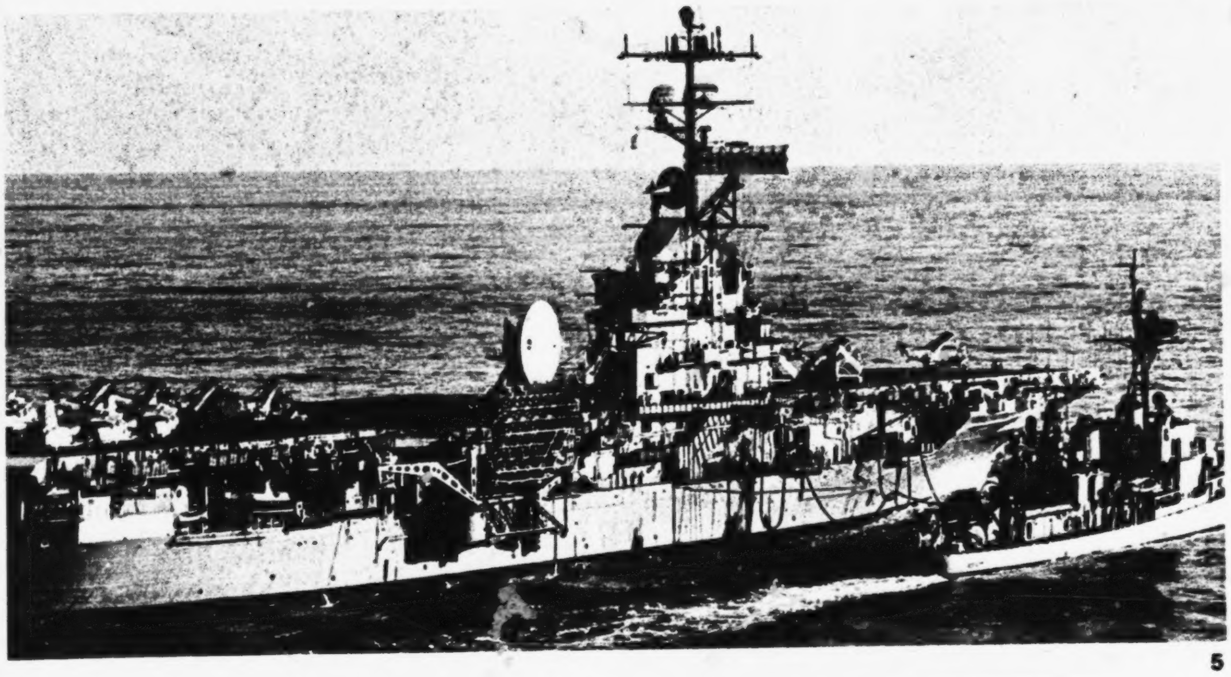
4. *Special camera effects show complex array of instruments in Gemini.*

5. *Aircraft carrier U.S.S. Wasp, prime recovery vessel for Gemini 6 and 7. Both spacecraft and astronauts were taken aboard this vessel after completing their missions.*

6. *Command module (crew section) of the Apollo spacecraft is hauled up in preparation for a test.*

7. *Photographs of earth taken from Gemini are proving immensely valuable to geographers, geologists, and oceanographers. Shown is the Wadi Hadhramaut region in Aden.*

8. *Journey's end. Astronauts Walter M. Schirra, Jr., and Thomas P. Stafford open their spacecraft hatches after landing Gemini 6 in the Atlantic Ocean on December 16, 1965.*



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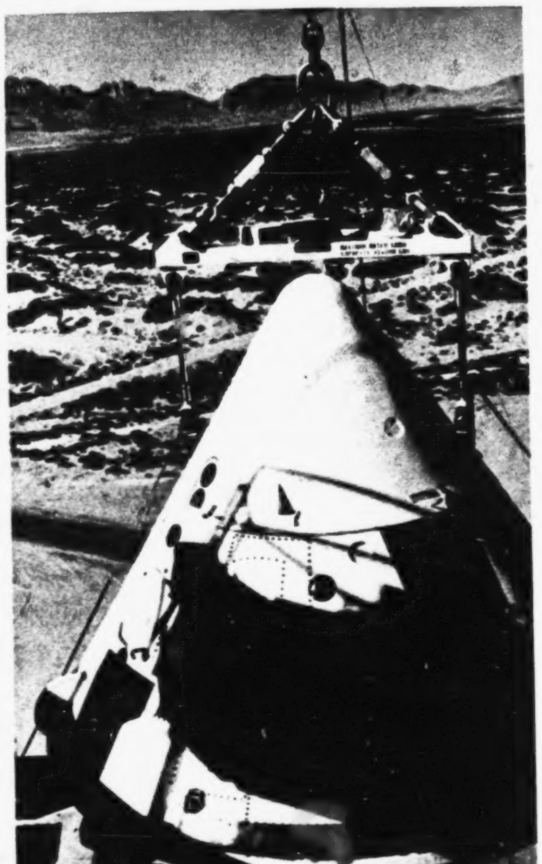

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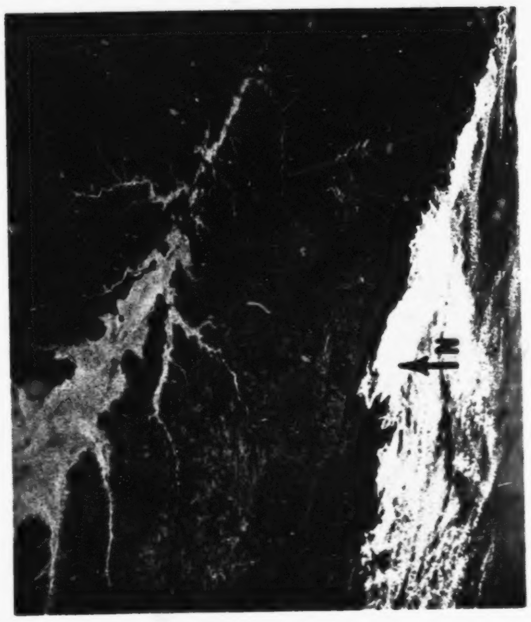

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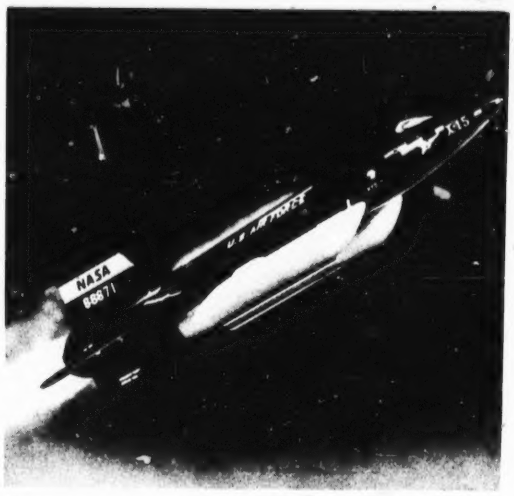
1. *Artist's concept of modified X-15 with external added fuel tanks.*
2. *The X-15 Research Airplane just before touchdown.*
3. *Nose of Gemini 8 spacecraft moves into docking collar of Agena rocket prior to historic docking (link-up) of March 16, 1966.*
4. *Artist's concept shows Apollo Lunar Module beginning its descent to the moon. The parent spacecraft (joined command and service modules) remains in lunar orbit.*
5. *Sequence of major events in Apollo lunar landing mission.*
6. *India and Ceylon as photographed from the Gemini XI manned spacecraft.*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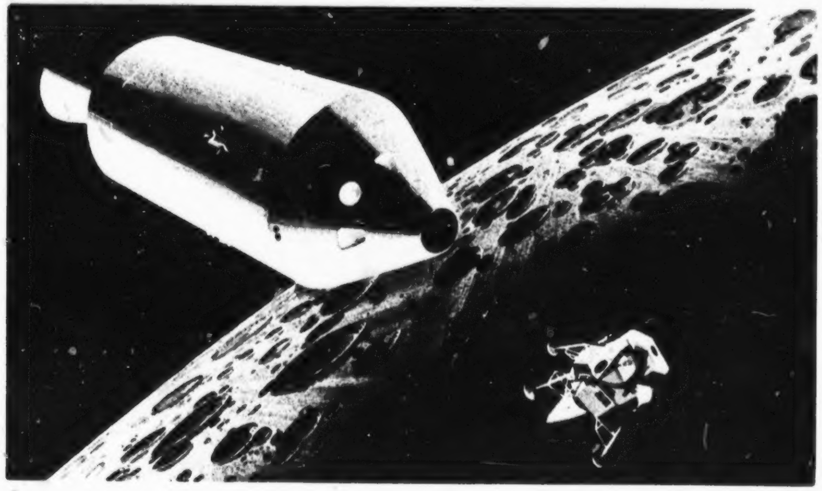

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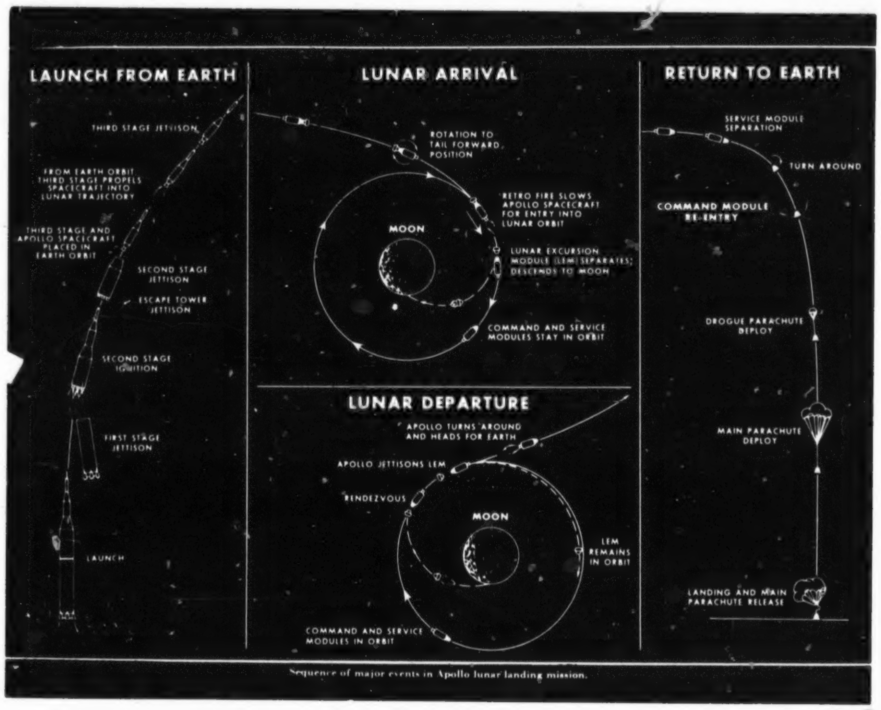
LAUNCH FROM EARTH
THIRD STAGE JETTISON
FROM EARTH ORBIT THIRD STAGE PROPELS SPACECRAFT INTO LUNAR TRAJECTORY
THIRD STAGE AND APOLLO SPACECRAFT PLACED IN EARTH ORBIT
SECOND STAGE JETTISON
ESCAPE TOWER JETTISON
SECOND STAGE IGNITION
FIRST STAGE JETTISON
LAUNCH
LUNAR ARRIVAL
ROTATION TO TAIL FORWARD POSITION
RETRO FIRE SLOWS APOLLO SPACECRAFT FOR ENTRY INTO LUNAR ORBIT
MOON
LUNAR EXCURSION MODULE (LEM) SEPARATES; DESCENDS TO MOON
COMMAND AND SERVICE MODULES STAY IN ORBIT
LUNAR DEPARTURE
APOLLO TURNS AROUND AND HEADS FOR EARTH
APOLLO JETTISONS LEM
RENDEZVOUS
MOON
LEM REMAINS IN ORBIT
COMMAND AND SERVICE MODULES IN ORBIT
RETURN TO EARTH
SERVICE MODULE SEPARATION
TURN AROUND
COMMAND MODULE RE-ENTRY
DROGUE PARACHUTE DEPLOY
MAIN PARACHUTE DEPLOY
LANDING AND MAIN PARACHUTE RELEASE
Sequence of major events in Apollo lunar landing mission.

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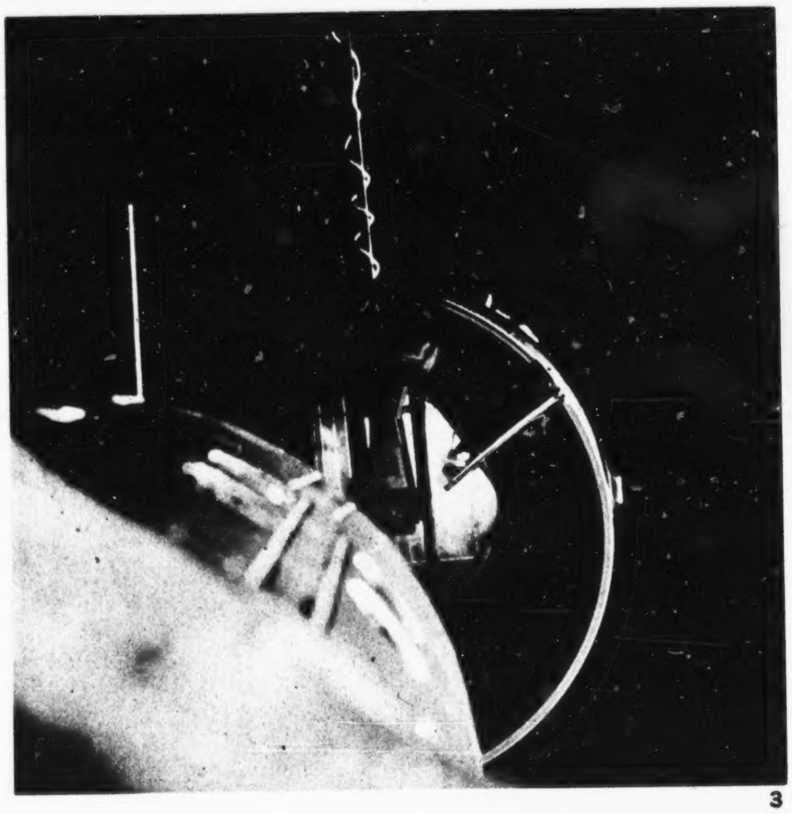
man remains with the parent craft, which continues to orbit the moon.

The two astronauts explore the moon's surface near their landing site, take pictures, collect samples, and conduct scientific experiments. Then, they enter their LM and launch it to a rendezvous with the parent craft. After the two astronauts have rejoined the other astronaut in the parent craft, they jettison the LM. Then, they fire a rocket in the service module to boost the parent craft out of lunar orbit toward earth.

One of the most critical phases of the return to earth is atmosphere entry. At a speed of 25,000 miles per hour (which is the earth-approach velocity of a spacecraft returning from a lunar mission), a spacecraft must follow an extremely precise course called an entry corridor to avoid burning up or bouncing back into space. The crew operates rockets in the service module to adjust Apollo's course properly. When they are in the entry corridor, they jettison the service module.

After the searing heat and heavy deceleration forces of atmosphere entry are passed, the command module opens first a small and then a large parachute to stabilize and slow the spacecraft for a landing. Recovery forces deployed in the expected landing area pick up spacecraft and crew for their triumphal return home.



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APOLLO APPLICATIONS A goal of the American space program is to gain preeminence in space. Another aim is to acquire the ability to fulfill any National need in space.

By using spacecraft, launch vehicles, and the technology developed for the Apollo manned lunar landing project, NASA can embark on further missions to expand man's horizons. Among missions being considered are:

- Extended lunar exploration from bases on the moon and from lunar orbit.
- Prolonged operations in earth orbit in, for example, manned space stations.
- Interplanetary exploration.

THE X-15 RESEARCH AIRPLANE The three X-15 research aircraft are designed as flying laboratories for engineering tests of aeronautics and space hardware and scientific tests. They are flown as a joint endeavor of NASA, the United States Air Force, and the United States Navy.

The X-15 scientific experiments have covered a wide range. Just a few:

- Observations of stars in ultraviolet light. Such information adds to our understanding of the nature, origin, and development of stars.
- Measurements of atmospheric density at high altitudes.
- Studies of meteoric dust particles.

The X-15 is also used to conduct substantial research on components and experiments for space vehicles. It has, for example, tested telescopic and other equipment for use in the Orbiting Astronomical Observatory program and a horizon-scanner for Apollo mid-course maneuvers. Experience with the rocket-powered X-15 has produced evaluations of man's ability to control high speed winged vehicles. It has provided much data on the physiological effects of extremes of speed, altitude, stress, gravity, and other factors on pilots of aircraft.

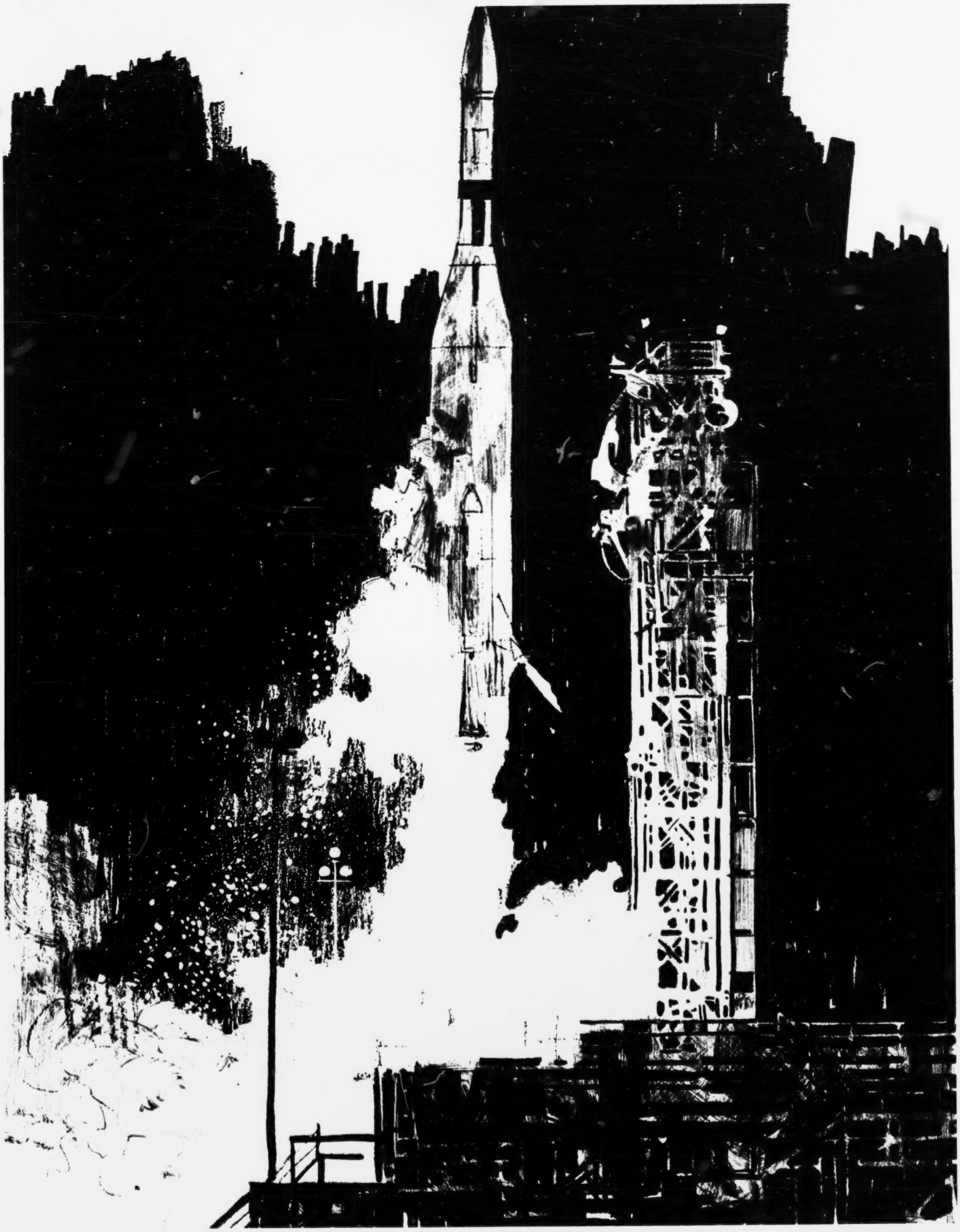
Work with the X-15 on structures, materials, instruments, and coatings has corrected or confirmed theory derived in the laboratory and in wind tunnels. It continues to serve as a test vehicle for future aeronautic and space projects. Originally designed for altitudes up to 250,000 feet and speeds as high as 4000 mph, the X-15 has reached a maximum altitude of 354,200 feet and a speed of more than 4200 mph. Additional fuel tanks increase substantially the maximum potential speed and altitude of one X-15.

The X-15 is propelled by a 57,000 pound thrust rocket engine. For attitude (orientation) control outside of most of the earth's atmosphere, the X-15 employs hydrogen peroxide jets. The X-15 is about 50 feet long and has a 22-foot wing span. It is carried aloft by a B-52 aircraft and launched at an altitude of about 42,000 feet.

The Space Launch Vehicles

IX

The United States has selected a fleet of launch vehicles to rocket its spacecraft into earth orbit and beyond. The range of vehicle capability is such as to permit selection of the one that most economically performs a specific mission. Their repeated use contributes to reliability. Moreover, a continuous developmental program is designed to upgrade the capability of each vehicle. ¶ Launch vehicles employed for NASA space programs: **SCOUT** A solid propellant launch vehicle, Scout can orbit a 240-pound satellite about 300 miles above earth. Scout has four stages and stands 72 feet high on the launch pad. **DELTA** Delta is a "work horse" NASA vehicle for a wide range of small payload satellite misions, with a long list of successful operations to its credit. Eight feet in diameter at its base and 90 feet long, Delta can place a 880-pound object into earth orbit, send a 150-pound probe to the moon, or rocket a 120-pound spacecraft to Mars or to Venus. It has three stages. **THRUST-AUGMENTED DELTA (TAD)** TAD is a Delta modified by the strapping of three auxiliary rockets to its first stage. The three rockets augment lift-off thrust from 170,000 pounds to 332,000 pounds. TAD can launch an 1185-pound satellite, send a 210-pound probe to the moon, or rocket 160 pounds to Mars or to Venus. **THOR-AGENA** Developed by the U.S. Air Force and adapted by NASA to civilian programs, Thor-Agena is a two-stage, 76-foot-high vehicle capable of placing 1600 pounds into a 300-nautical-mile orbit. **THRUST-AUGMENTED THOR-AGENA (TAT)** TAT, like TAD, increases its first-stage thrust from 170,000 to 332,000 pounds by addition of three strap-on rockets to its Thor first stage. The vehicle can launch satellites as heavy as 2200 pounds into a 300-nautical-mile orbit. **ATLAS D** Atlas D is a 1½ stage liquid-propellant vehicle. Its three engines, all of which are ignited at launch, provide about 388,000 pounds of thrust. The outer two engines, counted as a half stage, are jettisoned at the end of their burning time. The inner rocket, called the sustainer engine, burns until orbit is attained. The 72-foot-long Atlas D can launch a satellite weighing about 3000 pounds into an orbit approximately



100 nautical miles above earth.

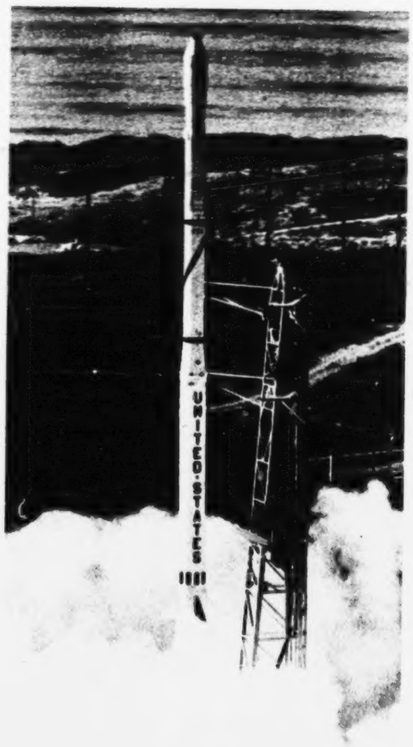
ATLAS-AGENA The Atlas-Agena was developed by the U.S. Air Force and adapted by NASA to civilian space programs. The 91-foot long two-stage rocket vehicle can place 5950 pounds into a 300-mile orbit, send about a thousand pounds to the moon, or rocket a 600-pound craft to Mars or to Venus.

ATLAS-CENTAUR Atlas-Centaur has an Atlas first stage and a second stage powered by two engines using a combination of liquid hydrogen and liquid oxygen. This propellant combination generates about 40 percent more thrust than would be produced by the same weight of conventional rocket fuels such as refined kerosene and liquid oxygen. Another feature of this second stage is that it can be stopped and restarted in space. Atlas-Centaur is designed to launch an 8500-pound satellite into an approximately 300-mile orbit, rocket a 2300-pound spacecraft to the moon, or launch a 1300-pound craft to Venus or to Mars. The vehicle is 100 feet long and has a maximum diameter of 10 feet. The upper stage is the first United States rocket vehicle to employ the high-energy liquid-oxygen liquid-hydrogen propellant combination.

TITAN II The Gemini launch vehicle is the Air Force Titan II, modified to fit the needs of the Gemini program. The vehicle utilizes a kind of liquid propellant that can be stored indefinitely in its fuel tanks. Thus, unlike other liquid-fuel rockets whose propellants must be held at cryogenic (intensely cold) temperatures, Titan II can be fueled well ahead of a launch and need not be drained of fuel if a launch is postponed. Titan II stands 90 feet tall and has a launch thrust of 430,000 pounds. It can place a spacecraft weighing about 8000 pounds into orbit around earth.

SATURN I On July 30, 1965, NASA completed a series of 10 successful flight tests with the Saturn I. The tests were designed to provide experience in and study of Saturn I performance to aid in development of the more powerful Uprated Saturn I and Saturn V launch vehicles. In conjunction with its developmental flights, Saturn I orbited boilerplate Apollo command and service modules and three Pegasus meteoroid satellites.

The two-stage Saturn I is 120 feet long and has a maximum diameter of 21.6 feet. It generates 1.5



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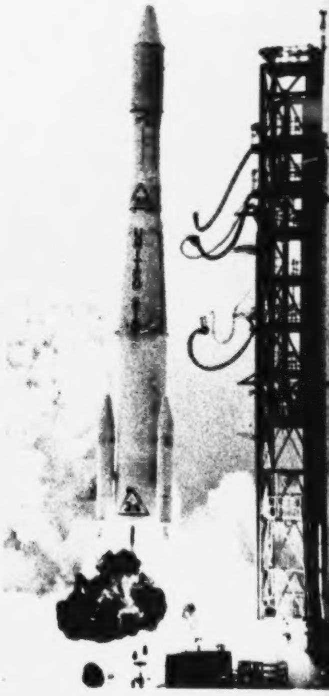


1. *Scout*

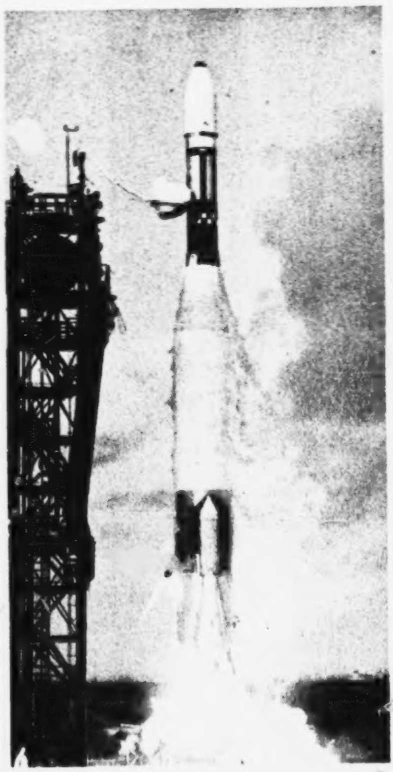
2. *Thrust-Augmented Delta (TAD).*

3. *Atlas-Agena*

4. *Atlas-Centaur*

5. *Thor-Agena*

6. *Atlas launches Mercury spacecraft.*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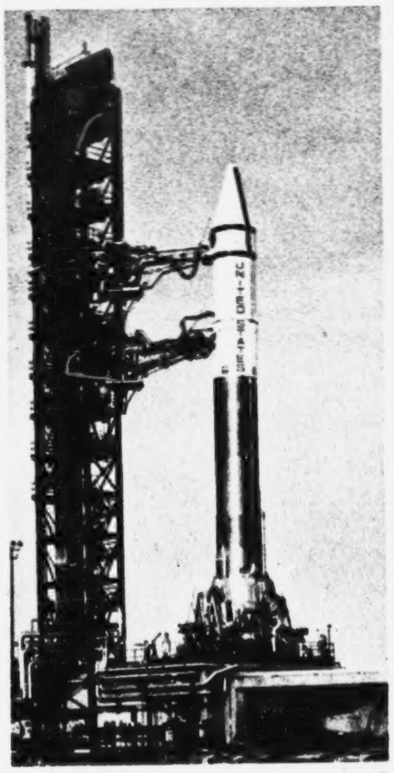
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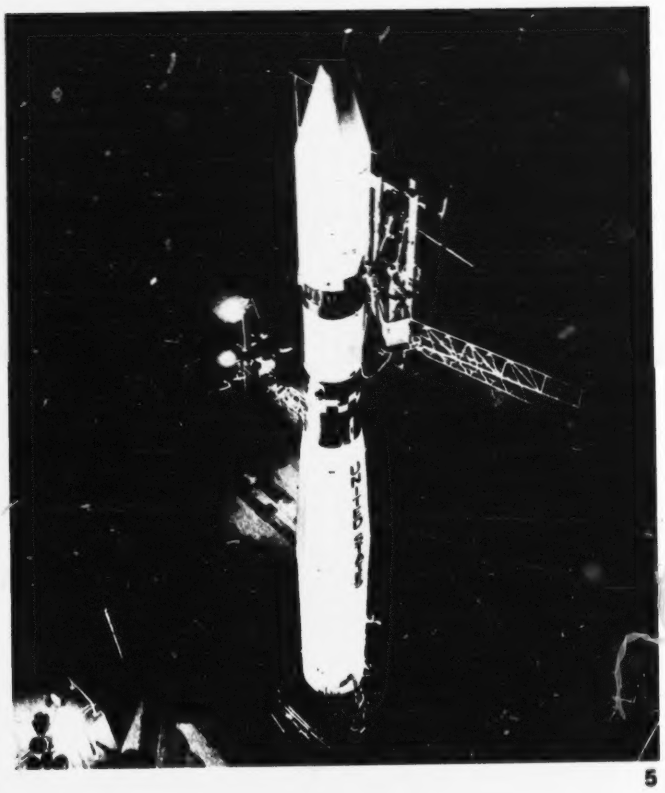
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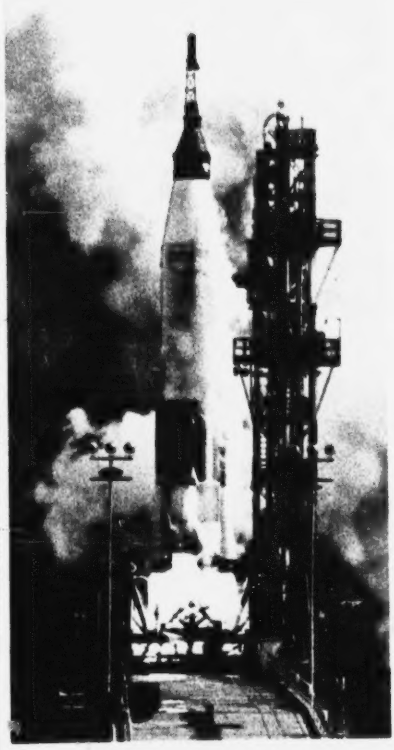
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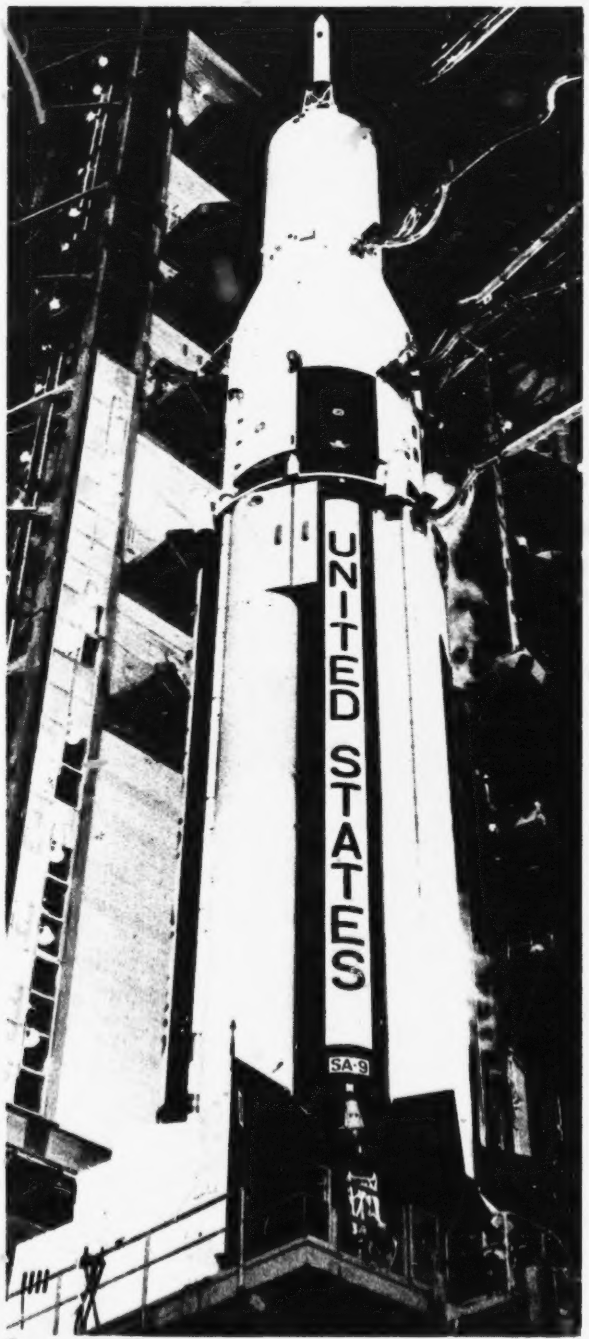

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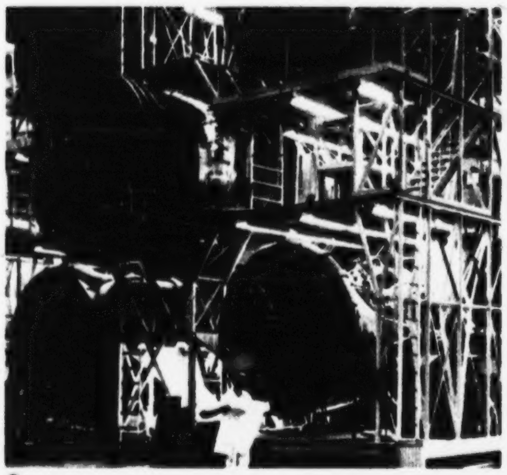
1. *Saturn I with Apollo test model.*

2. *Rocket nozzles of the first stage of the Saturn V poke out from the vehicle's assembly structure.*

3. *Titan II launches Gemini spacecraft.*

4. *Size comparisons—Saturn V, Uprated Saturn I, and Saturn I with men, vehicles, and the Statue of Liberty.*



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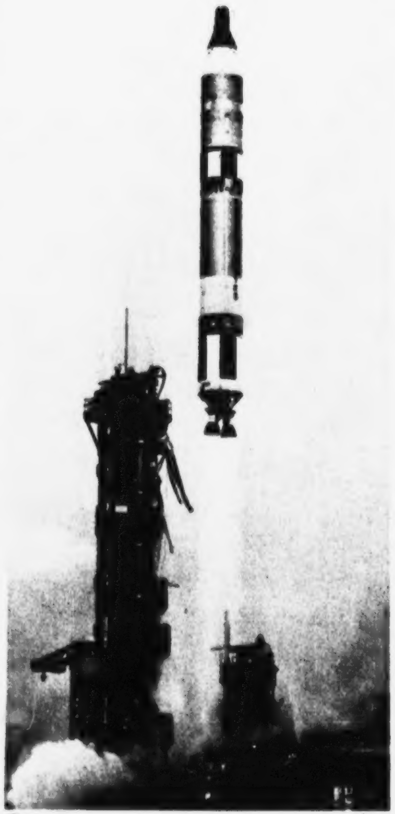

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million pounds of thrust in its first stage and can orbit a satellite weighing as much as 22,500 pounds.

UPRATED SATURN I This vehicle, employed in the rendezvous rehearsal phase of Apollo, has a first stage like that of Saturn I, except that its thrust has been uprated to 1.6 million pounds. The second stage is a liquid-hydrogen liquid-oxygen fueled rocket generating 200,000 pounds of thrust. The vehicle is 142 feet long. It can place more than 18 tons into earth orbit.

The Uprated Saturn I successfully passed its first flight test on February 26, 1966. This was a sub-orbital flight with an unmanned Apollo command module and service module.

SATURN V For the Apollo lunar exploration mission and certain unmanned interplanetary flight experiments, NASA is developing Saturn V, formerly called the Saturn C-5 or Advanced Saturn. Saturn V is the most powerful launch vehicle under development by the United States. Its first stage, about 33 feet in diameter (excluding fins), consists of five engines, each generating as much thrust as all eight engines of Saturn I. The aggregate thrust of these five engines is 7.5 million pounds. Upper stage powerplants consist of 200,000-pound-thrust rocket engines fueled by liquid hydrogen and liquid oxygen. Five of these make up the second stage; one, the third. Saturn V can launch a spacecraft weighing more than 280,000 pounds into an approximately 100-mile earth orbit. It can send a 95,000-pound spacecraft to the moon. At launch, with the Apollo spacecraft mounted on its third stage, the Saturn V will tower 365 feet high over Cape Kennedy, Florida.

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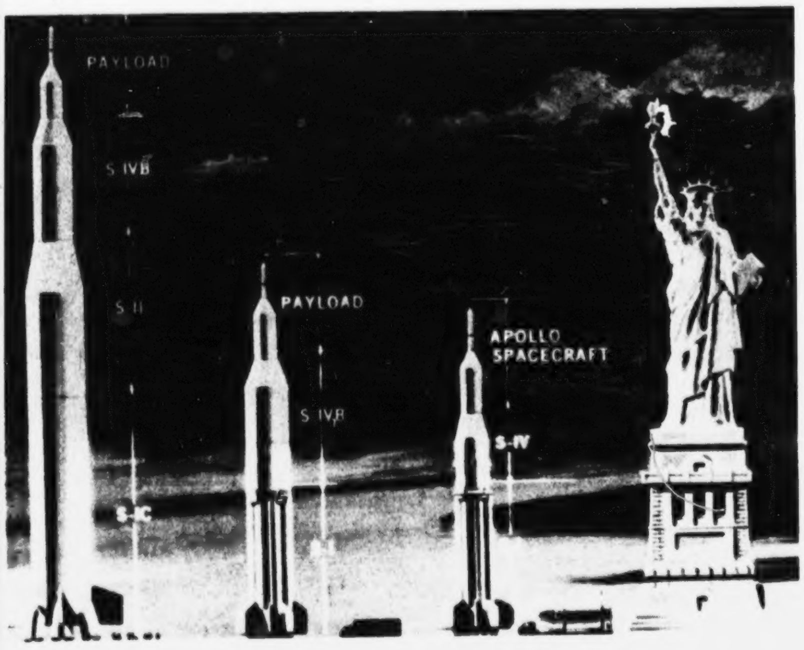

TABLE VI
EMPLOYMENT OF LAUNCH VEHICLES

Launch Vehicles	*Assignments*
Scout	Small Explorer satellites; ISIS; ESRO; San Marco; geoprobes; re-entry studies.
Delta and TAD	TIROS, TOS, and ESSA weather satellites; communications satellites (Telstar, Echo, and Syncom); and larger scientific satellites such as Explorers XII, XIV, XV, and XVII, Ariel, Orbiting Solar Observatories, the Interplanetary Explorers, Geos (Explorer XXIX); Pioneer; Early Bird.
Thor-Agena and TAT	Scientific satellites such as Alouette, Orbiting Geophysical Observatories; applications satellites such as Advanced Echo communications satellite and Nimbus weather satellite.
Atlas D	Project Mercury; re-entry research.
Atlas-Agena	Unmanned lunar and interplanetary probes such as Ranger, Lunar Orbiter, and Mariner; Orbiting Astronomical Observatory; Project Gemini; Applications Technology Satellite.
Atlas-Centaur	Surveyor spacecraft for soft landing on the moon; advanced Mariner spacecraft for exploration of Mars and Venus.
Titan II	Project Gemini.
Saturn I	Project Apollo earth-orbital flights of boilerplate command and service modules; Pegasus.
Uprated Saturn I	Project Apollo earth-orbital flights of command, service, and lunar excursion modules (complete Apollo spacecraft); orbital rendezvous rehearsals.
Saturn V	Project Apollo lunar exploration mission; under consideration for Voyager.

Biological Considerations in Space Exploration

X

WHAT MAN FACES IN SPACE To survive and fulfill his mission in space, man must be able to live there safely and in relative comfort. To do this he must create for himself in space an environment which will reasonably duplicate the one he is accustomed to on earth. ¶ Man is a complex mechanism, developed through thousands of years of living under one set of general conditions, i.e., in the earth environment. Although he can be trained and acclimatized, he cannot be reengineered. Hence, he must take his manner of living with him wherever he goes. This involves not only the air he breathes and the temperature and humidity he feels, but also protection from heat, cold, weightlessness, and radiation. In addition, there are the related problems of providing him with food and water and disposing of his waste. ¶ Man uses about two pounds of oxygen each day. This he gets, of course, from the atmosphere. In space, there is no atmosphere. For human breathing purposes, the atmosphere ends well below 50,000 feet. An aircraft pressurizes its cabin from surrounding atmosphere even at 40,000 feet, but because a spacecraft has no surrounding atmosphere, it must be pressurized from one of three sources carried along: compressed gaseous oxygen, liquid oxygen or chemical compounds which liberate oxygen. ¶ Dangerous radiation from the sun and from sources beyond our solar system is stopped or reduced in intensity before it reaches earth by earth's atmosphere and magnetic field. Comparable protection must be provided for man in space.

WHY MAN IN SPACE In view of the problems created when man travels into space, why must he go? Machines can be designed to do specific tasks in space. But man possesses remarkable sensors, and he is flexible. He can make decisions and perform in a manner required by the situation. He can screen data, systematize it, and recognize patterns. Machines can manipulate, but the difficulties of using machines as manipulators increase with distance. ¶ A machine designed for a specific expected task can do it more reliably than man, but man can respond to the unexpected. Much of what we find on other

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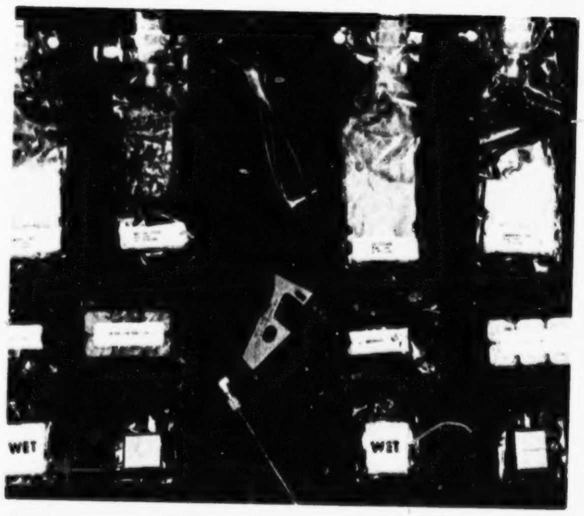
1. *Technician in Gemini spacecraft drinks water from balloon-like container.*

2. *Two complete Project Gemini meals and unusual ware for eating in space. The clippers are used to open the food bags. The pistol-like device squirts water into bags containing dehydrated food. The packages labelled "WET" contain treated face cloths for wash up after meals.*

3. *Wolf Trap.*

4. *NASA Scientist-Astronaut Joseph P. Kerwin models prototype Apollo space suit.*

5. *Biosatellite in space (artist's concept).*



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celestial bodies may be unexpected.

Moreover, the maintenance of complex equipment requires the presence of man in space.

Thus, as sensor, manipulator, evaluator, and engineer, the role of man grows with the scope and range of space activities.

ENABLING MAN TO LIVE AND WORK IN SPACE Automated systems are designed to support and extend human capacities in space. There are two major considerations in the employment of such equipment. One is whether the astronauts have time for the job the machine can do and whether they can perform the job as well or better. Another is that the equipment should be relatively easy to operate. Fundamentally, NASA is developing systems in which people and machines work together to best advantage.

Space suits have been fabricated that protect man from high vacuum, temperature extremes, small meteoroids, and radiation that he would encounter in space or on airless bodies such as the moon. They are constantly being improved for greater comfort and freedom of movement.

Zero gravity (weightlessness), limited space and other restrictions govern preparation of foods for space flight. For example, weightlessness can cause food and water to float about the cabin. As a result, food for space flight is prepared in special ways. Among them:

- Puree form, packaged in squeeze tubes.
- Dehydrated whole or sliced foods in plastic bags.
- Solid bite-sized chunks in edible wrappers.
- Powdered (like powdered milk or instant coffee) in plastic bags.

Water is packaged in squeeze tubes.

The development of tools for astronauts to use in space calls for a different approach from that used in manufacturing tools for earth use. The problem arises because of zero gravity.

One of Newton's laws of motion is that for every action, there is an equal and opposite reaction. When we tighten a nut or turn a screw on earth, we do not notice this phenomenon because of our weight, or earth's gravity.

In space, however, where man is weightless, he would start whirling in the direction opposite to which he was turning a nut. To cope with this problem, man must be secured to the spacecraft, perhaps by a belt like that which a telephone lineman uses on a pole; or he must be provided with tools that absorb or neutralize the reaction forces before they reach him.

NASA has already developed several prototype space tools which tend to neutralize reaction forces. It is also studying mechanical as well as electrical and magnetic devices that can temporarily hold the astronaut to the outside of a spacecraft so that he can perform useful work and does not drift away.

RESEARCH FOR SPACE FLIGHT OF LONG DURATION Within this century, space flights lasting from several months to several years may be a reality. Sustaining men for such long periods calls for significant advances in science and technology. This is because supplies for these missions could take up tremendous amounts of weight and space.

For such missions, mechanical and chemical systems that repeatedly recycle elements will be used. On earth, we have a natural system of this type. Food, water, and air are recycled and replenished again and again. An artificial system currently under development recovers oxygen and water and removes toxic substances. However, reconstitution of food is beyond the technological state of the art for the foreseeable future.

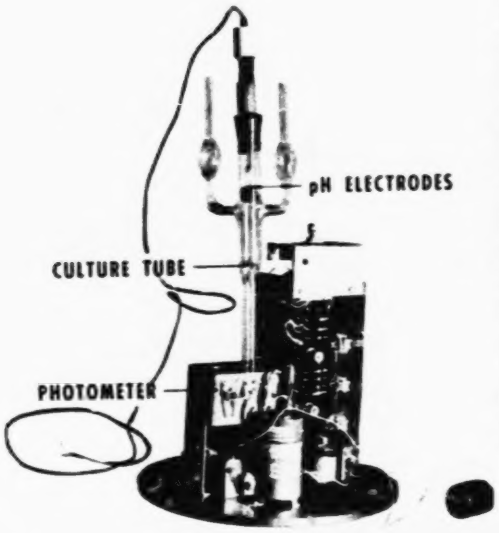
To alleviate the problem of food storage, dehydrated foods have been developed. Studies are being made on advanced dehydration and compression techniques in which foods are reduced to one third of their normal dehydrated, or dry, volume.

This makes possible the storage of a 45-day solid food supply in the space formerly set aside for a 15-day supply. With hot water, the food can be restored to its normal size and palatability in several minutes.

There are many other considerations. Among them is that man is accustomed to a certain day-night cycle and that he performs best when he works, eats, and sleeps in his usual manner. He must have room to shift his position, preferably to walk about. He must be able to make adjustments in his environment to suit his needs. He must have a way to solve the problem of fatigue, the kind of fatigue that is derived from overlong commitment to one task and confinement within a small area. Such fatigue can impair judgment, reduce alertness and perception, and increase irritability and indecision.

A major area of specific research is the kind of cabin atmosphere that should and can be provided for long term space flight. Experimenters are studying the possible effects of different gases on the crew. Pure oxygen has been used successfully for the relatively short Gemini missions. However, laboratory studies indicate that pulmonary (lung) damage can be caused by breathing pure oxygen for a long period. Studies are being made on the long-term effects of breathing pure oxygen and combinations of oxygen and inert gases (such as helium) at different pressures.

Another possible problem area is weightlessness. If it is found that man cannot adapt to long-term weightlessness, then one engineering solution is to rotate the spacecraft. The resulting centrifugal force would provide some gravity, or weight. Laboratories on the ground are studying the effects of different rotation rates on human performance and well-being.



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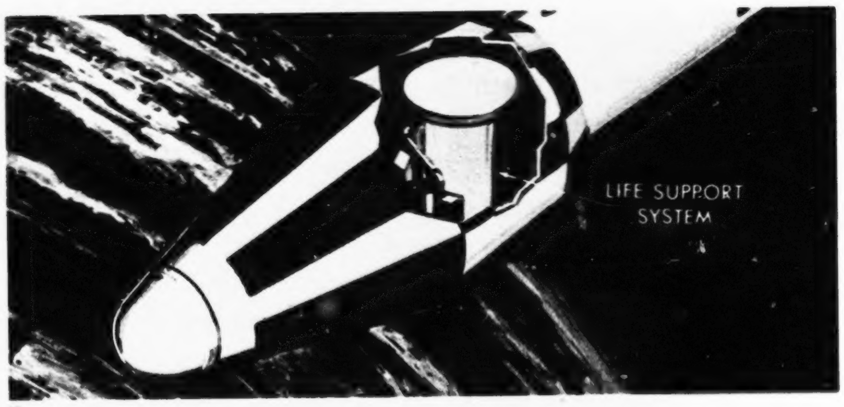

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Among reactions to weightlessness observed in astronauts on early space flights were increases in white blood cells, decreases in red blood cells, reduction in bone calcium, and circulatory difficulties upon return to earth. Doctors were particularly interested in the medical reactions of Astronauts Borman and Lovell during their 14-day Gemini space flight of December 4-18, 1965. They found that these reactions were less intense than those of astronauts in previous shorter flights. This finding suggests that man's body may be able to adapt to longer flights in space.

Moreover, this space mission, which is the longest on record to that date, produced no seriously adverse effects on the astronauts. Several factors are believed to have contributed to this result. Among them were that the astronauts managed to eat and drink properly, to sleep at regular intervals, and to relax by taking off their space suits for part of the time.

NASA's Mariner II spacecraft which passed Venus in December 1962 and Mariner IV which took relatively close-range pictures of Mars in July 1965 provided data about the levels of radiation in space. Both spacecraft reported radiation levels that appear to be within the limits of shielding that can be provided man during the periods of travel involved. The amount of radiation is still considerably above that encountered at earth's surface. Engineers are considering various means of shielding men against radiation. Also under study are special ways to protect astronauts against the very high intensities of radiation that may flood space after a large solar flare.

One suggestion is the creation of an artificial magnetic field around the spacecraft. It would function somewhat like earth's magnetic field which shields earth from much radiation that streams toward this planet from outer space.

Correct information about the environments to and through which man must travel is vital to planning for man's well-being during such voyages. As a result, crewless spacecraft such as Ranger, Surveyor, Lunar Orbiter, Mariner and Voyager are preceding man to the moon and to Mars and Venus. Orbiting Solar Observatories, Pioneers, Biosatellites, and Interplanetary Explorers are among the vehicles designed to furnish additional required data on space radiation and other phenomena.

THE SEARCH FOR EXTRATERRESTRIAL LIFE

In a related program, NASA is investigating the possibility of life elsewhere than on earth. Life normally results where the conditions for it are appropriate. However, most scientists agree that the appropriate conditions need not necessarily resemble those on earth nor must all life be comparable to earth forms.

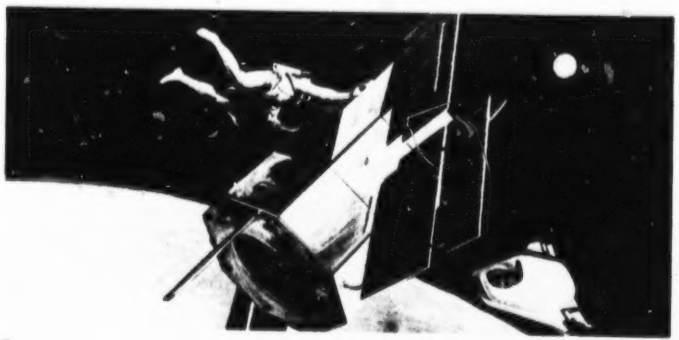
The conditions of space are simulated in earth-based laboratories. Micro-organisms are inserted in simulators to determine whether and how long organisms can survive the temperature extremes, high vacuum, and radiation of space. The results of these studies may have important implications relative to life on other planets.

Life scientists have simulated in the laboratory the kind of environment believed to exist on Mars. They have discovered that certain terrestrial lichens, mosses, and bacteria can survive for a limited time in this kind of environment. This does not necessarily mean that such organisms live on Mars but that organisms such as these could live on Mars. In the opinion of scientists, Mars is the best candidate in the solar system for some sort of life like that on earth.

Balloon-borne instruments have made infrared studies of Mars. These and other studies detected minute quantities of water vapor and considerable carbon dioxide in the atmosphere. Their existence suggests the possibility that specially adapted lower forms of life may exist on the Red Planet.

During its exploration of the moon, NASA plans to analyze lunar materials for signs of life. Such analysis may disclose remnants of extinct life or organic substances that might signify the presence of life. On the other hand, the study may bring to light prelife chemicals (chemicals identified with life) that have accumulated through natural processes over millions of years but have not been organized into living things. Such a find would be invaluable to the study of how life originated or evolved.

As a part of this program, NASA is supporting the examination of meteorites for organic compounds. It is also studying the origin of compounds of living organisms under primeval geo-



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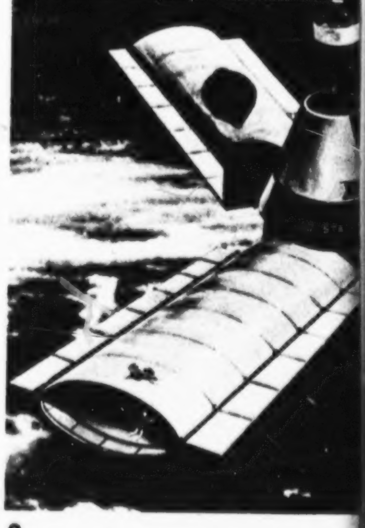
1. *Repairing an Orbiting Astronomical Observatory (artist's conception).*

2. *Artist's concept of a possible future orbiting space station in which men would work for long periods.*

3. *Multivator, left, unassembled showing insides. Right, assembled.*

4. *Gulliver*



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chemical conditions. These studies, by increasing understanding of life processes, may contribute to identifying life forms on other planets that may be very different from those on earth.

With reference to the latter, NASA has already synthesized in the laboratory the five chemical building blocks of life's reproductive molecules, DNA and RNA.[1] Such synthesis was accomplished using only simple ingredients and duplicating conditions that theoretically existed on earth from three to four and one half billion years ago.

Generally, the scientists used methane, ammonia, and water (believed to make up the primeval earth's atmosphere), inorganic phosphates, 180° F. heat (representing results of volcanic eruptions), and electric sparks (representing lightning). The five DNA-RNA building blocks, known as nucleotides, are each made up of a nitrogenous base, a sugar, and a phosphate.

Hundreds of thousands of nucleotides are linked together in chains of DNA and RNA, which direct the reproductive processes of life. Such linkage has not yet been accomplished in any laboratory. Other scientific organizations have created the same nucleotides that NASA has but have used long and complex processes such as high temperatures which probably did not exist on earth when life began.

Research is in progress to find catalysts which may have existed on the primeval earth and can generate long DNA and RNA chains. Such research is bound to lead to greater understanding of important processes of the human body.

Several life detection devices are being considered for landing on other planets. These minature laboratories are primarily designed to report on microbial life. They are quite small, and some weigh as little as 1½ pounds.

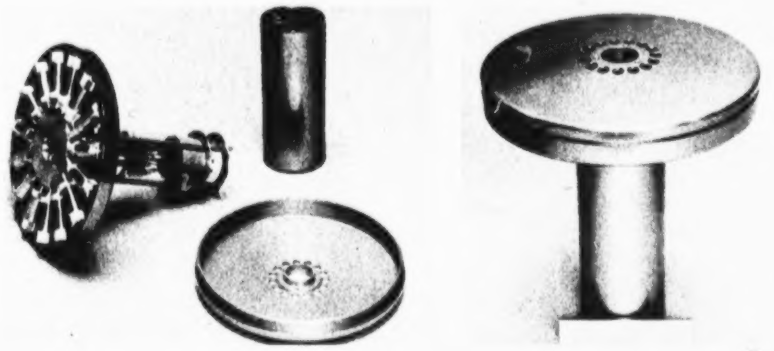
One is named *Gulliver* for Jonathan Swift's fictional discoverer of the tiny Lilliputians. After landing, Gulliver will fire adhesive cords outward and then reel them in. It is expected that dust and other surface substances will adhere to the cords. The cords will be immersed into or drenched by a nutrient solution containing radioactive carbon. If earthlike organisms are present, they will ingest and ferment the solution, creating radioactive carbon dioxide gas. This would be registered by a Geiger counter and the exciting results transmitted to earth.

Another device, which operates on a similar principle, is the *Wolf Trap,* named for its designer Dr. Wolf Vishniac. The Wolf Trap will suck in samples of soil and air and immerse them in nutrient solutions. If the samples contain organisms, the solutions will undergo changes in acidity and turbidity which would be reported to earth.

A third life-seeking instrument is the *Multivator.* The Multivator is a miniature laboratory that can carry out a dozen or more experiments to determine whether there are living things on Mars or other celestial bodies. Any such evidence will be quickly relayed to earth.

Other life-detection devices intended for landings on other planets are under study. Among them are:

- A TV-wired microscope for sending pictures of microscopic phenomena on the planet back to earth.
- A TV-wired telescope to survey the landscape of the planet on which it lands. Moving or swaying objects picked up by this telescope may be living things.



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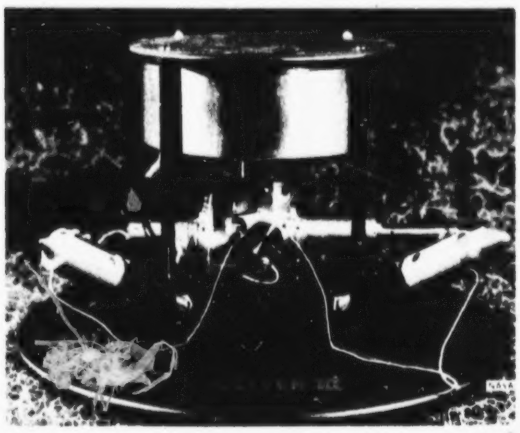

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[1] Common abbreviations for deoxyribonucleic acid and ribonucleic acid.

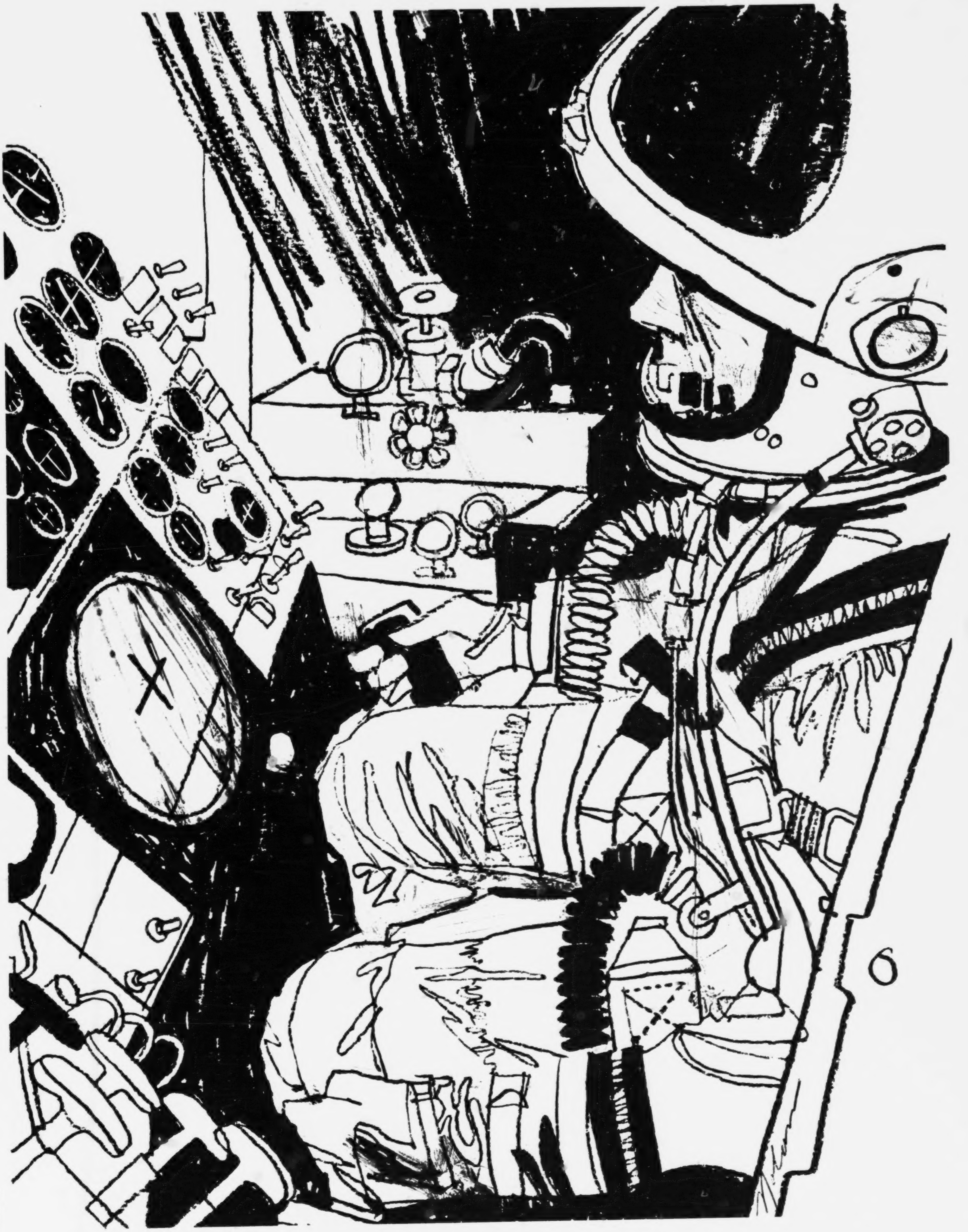
Astronaut Selection & Training

XI

The selection and training of pilots are as important as development of spaceworthy craft. The expected demands on man in space call for rigorous standards. The astronauts not only must be capable of meeting and familiarizing themselves with the considerable expected requirements of each space mission but also must possess the judgment and presence of mind to cope with the unexpected.

SELECTION Generally, astronauts are recruited on two bases: as pilot-astronauts and as scientist-astronauts. High physical and mental standards are among the criteria for selection of each group. ¶ There are other basic qualifications. For example, the first seven pilot-astronauts, who came to be known as the Mercury astronauts, had to: have an engineering degree or its equivalent; be under 40 years of age and not taller than 5 feet 11 inches; weigh no more than 180 pounds; and have a total of at least 1500 hours experience piloting jet aircraft. ¶ The standards for selection of other pilot-astronauts were for the most part similar to those used for the Mercury astronauts. However, the academic requirements were broadened to make eligible those with degrees in biological or physical sciences and the maximum age was reduced to about 35 years. For example, the group of pilot-astronauts selected in April 1966 had to be born on or after December 1, 1929. The jet flying experience requirement was reduced to 1000 hours. ¶ NASA's first scientist-astronauts were appointed in June 1965. Among the criteria used were that they had to meet the physical and psychological standards required of pilots; they had to have a bachelor's degree from an accredited university; and they had to have a doctorate, or the equivalent in experience, in the natural sciences, medicine, or engineering. (Those who were not qualified pilots were given training in high-performance jets and helicopters.)

TRAINING The astronaut training program is one of the most taxing physical and mental curricula ever devised. The astronauts must familiarize themselves with the functioning of every piece of spacecraft equipment. They must



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1. *Astronaut Carpenter runs on treadmill in stress test.*

2. *Astronaut Schirra uses mirror to signal as part of survival training.*

3. *Astronauts Scott (left) and Chaffee discuss a rock sample during field training in geology at Philmont Ranch in New Mexico.*

4. *Astronaut McDivitt in Apollo-type suit studies interior layout of mock-up of Apollo Lunar Module. This module will be detached from the parent Apollo spacecraft and landed on the moon.*

5. *Astronaut Conrad in a drop-test vehicle is helping engineers to devise the best safety-belt system for the Lunar Module.*

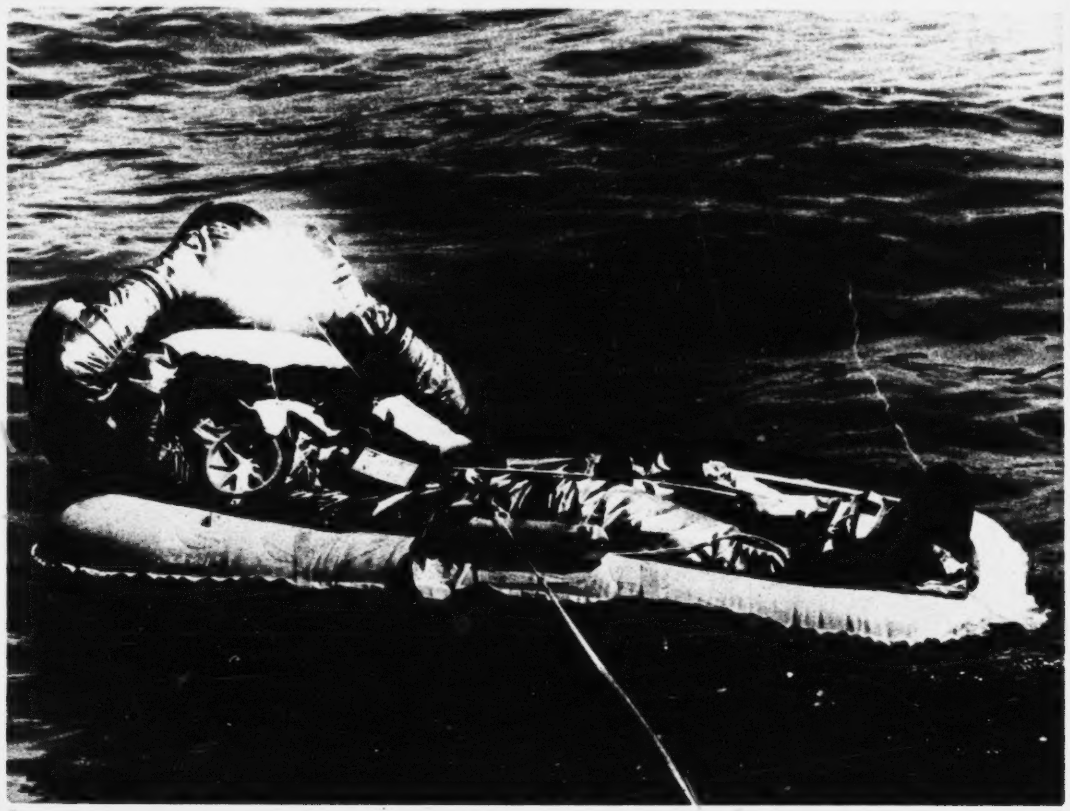
6. *Six scientist astronauts named in June 1965. Front row, l. to r.: Owen K. Garriott (physicist); Harrison H. Schmitt (astrogeologist); and Edward G. Gibson (physicist). Back row, l. to r.: F. Curtis Michel (physicist); Duane E. Graveline (physician); and Joseph P. Kerwin (physician).*

7. *Astronaut White uses a celestial sextant during astronomy navigation training at Moorehead Planetarium. This kind of sextant uses star positions as an aid to determining locations.*

8. *Seated are the original Project Mercury astronauts chosen in April 1959 (l. to r.): L. Gordon Cooper, Jr.; Virgil I. Grissom; M. Scott Carpenter; Walter M. Schirra, Jr.; John H. Glenn, Jr.; Alan B. Shepard, Jr.; and Donald K. Slayton. In the rear, standing, is the second group of astronauts, selected in September 1962 to join the Mercury astronauts in the larger Gemini and Apollo programs (l. to r.): Edward H. White, II; James A. McDivitt; John W. Young; Elliot M. See, Jr.; Charles Conrad, Jr.; Frank Borman; Neil A. Armstrong; Thomas P. Stafford; and James A. Lovell, Jr.*

9. *Astronauts selected in October 1963 are (seated l. to r.): Edwin E. Aldrin, Jr.; William A. Anders; Charles A. Bassett, II; Alan L. Bean; Eugene A. Cernan; and Roger B. Chaffee. Standing (l. to r.): Michael Collins; R. Walter Cunningham; Donn F. Eisele; Theodore C. Freeman; Richard F. Gordon, Jr.; Russell L. Schweikart; David R. Scott; and Clifton C. Williams, Jr.*

10. *Seventeen of the 19 pilot-astronauts chosen in April 1966. Front row, l. to r.: Donald L. Lind; Jack R. Lousma; Thomas K. Mattingly; Bruce McCandless II; Edgar D. Mitchell; William R. Pogue; Stuart A. Roosa; John L. Swigert, Jr.; Paul J. Weitz and Alfred M. Worden. Rear row, l. to r.: Vance D. Brand; John S. Bull; Charles M. Duke, Jr.; Joe H. Engle; Ronald E. Evans; Fred W. Haise, Jr.; and James B. Irwin. Seated next to Irwin is Donald K. Slayton, one of the original seven Mercury astronauts, who is Assistant Director for Flight Crew Operations at Manned Spacecraft Center, Houston, Texas. Two astronauts not shown are Edward G. Givens, Jr., and Gerald P. Carr.*



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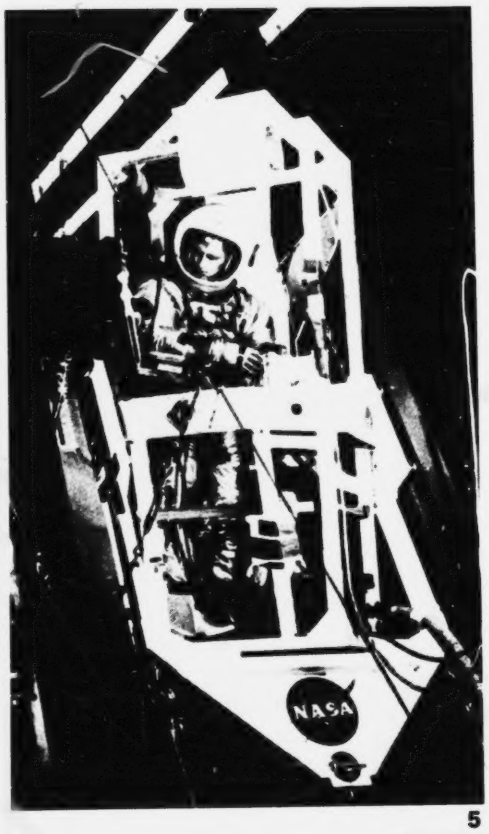

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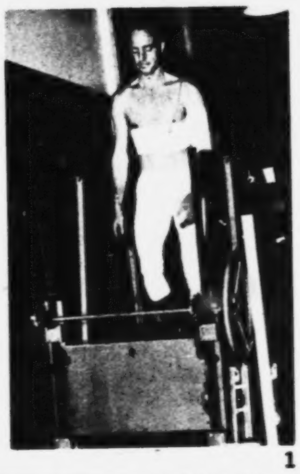

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MANNED SPACECRAFT CENTER
NASA
MAJ. JAMES B. IRWIN
DONALD K. SLAYTON
CAPT. STUART A. ROOSA
JOHN L. SWIGERT
LT. CDR. PAUL J. WEITZ
CAPT. ALFRED M. WORDEN

10

6

learn the technology of launch vehicles, ground facilities, and flight operations. They must learn how to check out and launch their craft, join with another in orbit while speeding at thousands of miles per hour, land by use of rocket power on the airless moon, control their craft during the fiery entry into earth's atmosphere and land it at a precise point on earth, using only the inherent lift of their craft and parachute.

They learn navigation by the stars, study geology in texts and go on field trips to observe various types of volcanic and other geologic formations so that they can recognize and report on them if such formations exist on the moon. They engage in survival tests in deserts, jungles, and seas. They practice removing themselves from their spacecraft under any condition. They spend time in centrifuges where they experience forces as high as 16g (16 times earth's gravity) and in other devices that spin and whirl them in many directions while they attempt to orient a simulated spacecraft. They enter vacuum chambers in space suits.

In all, they attempt to learn how to respond to any kind of condition or problem which may arise and to make full use of their mission for the extension of man's knowledge.

Rocket Propulsion Principles & Techniques

XII

In the 17th century, Sir Isaac Newton expressed three laws of physical motion. They are: 1. A body remains at rest or in a state of motion in a straight line unless acted upon by an external force. 2. A force acting upon a body causes it to accelerate in the direction of the force, the acceleration being directly proportional to the force and inversely proportional to the mass of the body. 3. To every action, there is an equal and opposite reaction. ¶ The third law contains the fundamental principle by which jet and rocket engines operate. In any kind of jet or rocket engine, the *action* is the stream of gas rushing through the exhaust nozzle. There is simultaneously created a *reaction* of equal force in the direction opposite to the flow of gas—which is the direction in which the vehicle is made to move. ¶ In a jet engine, such as those powering many of today's airplanes, the escaping gas is created when fuel and air are mixed. The air provides the oxygen for burning the jet fuel. ¶ The rocket engine can operate in space where there is no air because its propellant tanks carry a supply of oxygen. As the fuel and oxygen are mixed and expelled as hot gases, they produce a continuous force. The rocket accelerates as long as this force persists, in accordance with Newton's second law.

ROCKET ENGINE PERFORMANCE There are a number of measures of rocket performance which need definition. They include—

THRUST—This is the reaction force exerted on the vehicle by the rocket jet, or the "push." Two major factors determine the amount of thrust: the rate at which the propellants are burned and the velocity at which the resulting gases are exhausted. Thrust is measured in pounds. ¶ The thrust of a rocket vehicle launched from the ground must be greater than the loaded weight of the vehicle. Thus, if large masses are to be lifted from the ground into an orbit about the earth or ejected farther into space, correspondingly large thrusts are required. When a specific job permits a small payload, a low thrust will suffice to accomplish the mission.

THRUST-TO-WEIGHT RATIO—This ratio is a comparison of the engine thrust with the vehicle's total weight. It is particularly significant, because thrust alone is not indicative of a vehicle's potential for velocity or range. Ten million pounds of rocket thrust will not lift a 10-million-pound vehicle from the ground. Yet, if the vehicle that weighs 10 million pounds on the ground is already in orbit where it is weightless, a few pounds of thrust applied for an extended period can accelerate it eventually to tremendous velocities. ¶ As an example of thrust-to-weight ratio, let us take the Saturn V-Apollo combination. The entire assembly will weigh about 6 million pounds at launch. First stage thrust is 7.5 million pounds. Thus, the thrust-to-weight ratio at launch is 7.5 to 6 or, mathematically reduced, 5 to 4 or 5:4. This ratio will change as the vehicle gains altitude, because thrust increases as atmospheric pressure drops and weight decreases as propellants are consumed and distance from the ground becomes greater.

SPECIFIC IMPULSE—Specific impulse is the amount of thrust derived from each pound of propellant in 1 second of engine operation. It is expressed in seconds. Specific impulse means to the rocket engineer much the same as does miles per gallon to the motorist; it is a measure of the efficiency with which the rocket propellants are being used to generate thrust. ¶ Greater specific impulse means that more push is derived from each pound of propellant. This can make possible reduction in amount or weight of the propellant required for a given mission and permit a decrease in size and weight of propellent tankage. On the other hand, greater specific impulse enables a rocket to launch heavier payloads and send them farther into space. ¶ Most of today's rocket engines burn a mixture of refined kerosene and liquid oxygen that has a specific impulse of 300 seconds. The Atlas-Centaur and the Saturn-group launch vehicles have upper stages burning liquid hydrogen and liquid oxygen, providing a specific impulse of 400 seconds. ¶ Eventually, nuclear rockets with a specific impulse of 800 to 1000 seconds may become available. Beyond this are ion rockets theoretically having specific impulses of 10,000 to 15,000 seconds. (See "Future Propulsion," below.)

EXHAUST VELOCITY—Exhaust velocity of a rocket denotes the speed at which the jet gases are expelled from the nozzle. This exit speed depends

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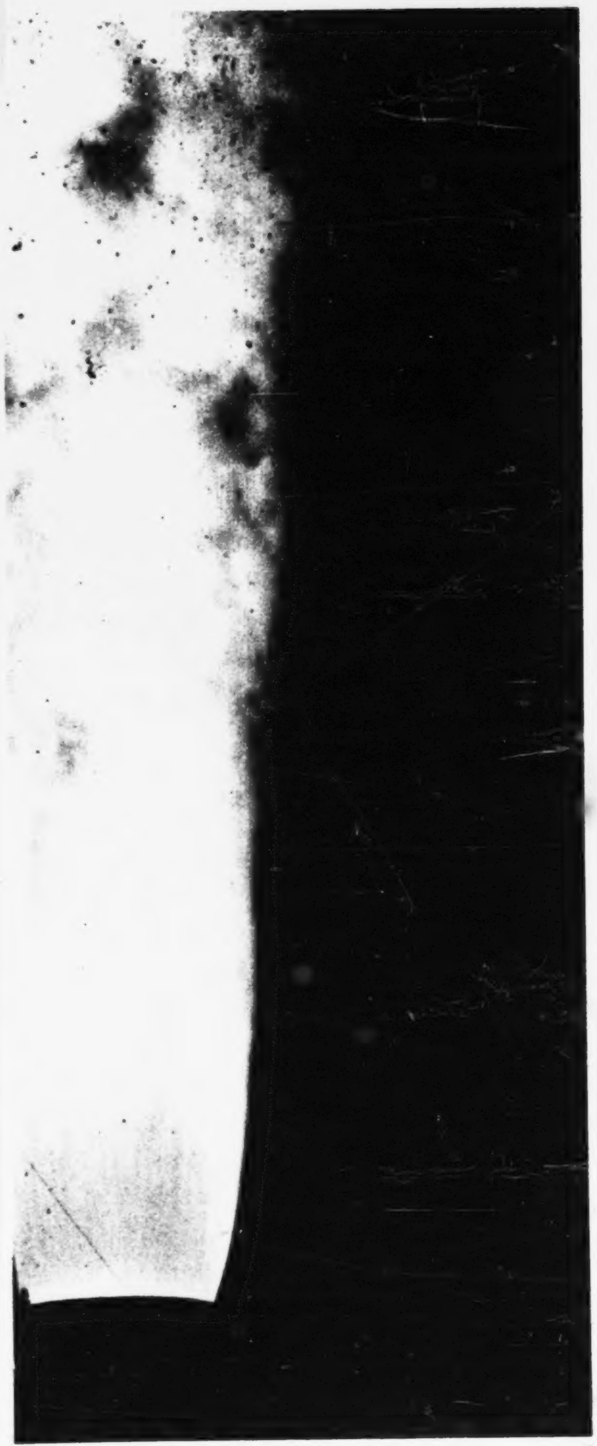

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1. *Bolted nozzle end upward in a deep pit, the 260-inch diameter solid-fueled rocket is test fired.*

2. *Solid rockets attached to the first stage of standard launch vehicles significantly increase their capabilities. Shown is part of the first stage of the Thrust-Augmented Delta.*

upon propellent-burning characteristics and overall engine efficiency.

MASS RATIO—This is the relationship between a rocket vehicle and the propellant it can carry, obtained by dividing the total mass at takeoff by the total mass remaining after all propellants are consumed. High mass ratio and high exhaust velocity or specific impluse are the most important factors in determining the velocity and range of a vehicle, hence the most important goal of rocket research.

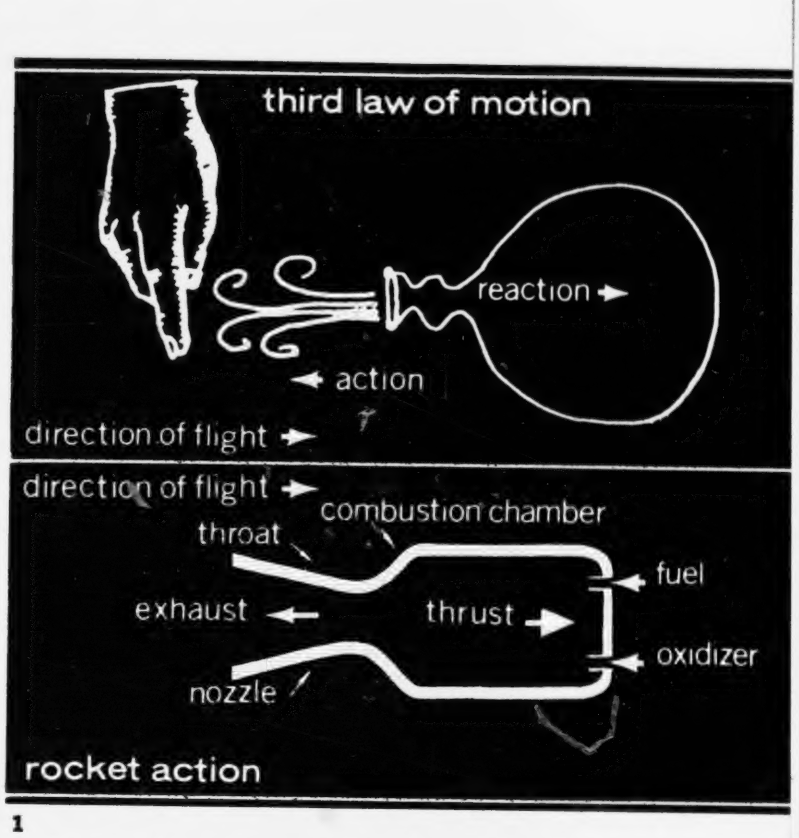
Excluding the effects of gravity and air resistance, a rocket vehicle with a mass ratio of 2.72 to 1 will achieve a speed equal to its exhaust velocity. A 7.4-to-1 mass ratio, considered feasible for single-stage rockets, will produce vehicle speeds of twice the exhaust velocity. A 20-to-1 ratio would produce speeds three times the exhaust velocity, but this would require a structure, including payload, amounting to no more than 5 percent of the total takeoff weight and it is not likely that such a structure could stand up under the stresses of vehicle operation.

Inasmuch as the improvement of mass ratio improves the total rocket vehicle performance, then any device by which useless mass can be eliminated as soon as it is no longer needed should improve the performance of a rocket. This is the idea behind the so-called "step" or multistaged rocket.

In such a vehicle a series of rockets are mounted on each other. The first rocket fires, carrying the remaining rockets up to its terminal velocity. At the end of its burning, the first rocket is discarded, thereby reducing the overall mass of the combination, and the second rocket is ignited. After the end of the burning of the second rocket, it is discarded in turn, and the third rocket is ignited.

This is continued for as many stages as are used in the combination. By this device the overall mass ratio of the combined system is improved far beyond that obtainable in single-stage vehicles. Roughly, the mass ratio of the combination is equal to the product of the mass ratio of the individual stages.

It is obvious from the foregoing that design of a vehicle for space exploration is an extraordinarily complex task. The designer must take into consideration the weight, volume, and energy potential of a propellant; the weight, shape, and volume of the vehicle structure; the weight and volume of the payload; the weight and power of the engine or engines; and the effects of atmospheric resistance and gravity.



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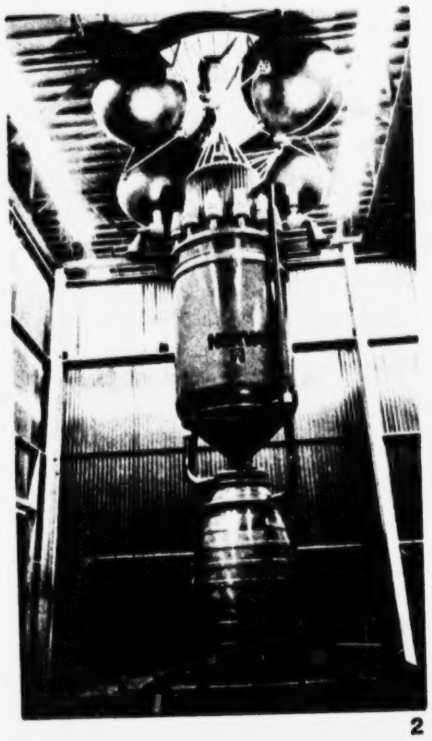
1. *The third law of motion. Note that the balloon and the rocket do not fly because of the escaping gases. They fly because the gases streaming rearward are producing an equal force in the opposite direction (on the balloon's and rocket's inner front surfaces).*
2. *Mock-up of NERVA, a nuclear-powered rocket engine.*
3. *The Titan II, which uses hypergolic fuels, stands ready to launch a Gemini spacecraft. The erector, which raised Titan into position is being lowered away.*
4. *Conceptual interplanetary spacecraft. Nuclear power may be the key to manned exploration of the solar system.*
5. *Ion rocket engine ejects stream of ions during test.*
6. *Hydrogen-fueled upper stage of Atlas-Centaur launch vehicle.*

ROCKET PROPELLANTS IN USE Current rocket propulsion systems are based on the use of chemical propellants, which may be either liquid or solid.

In a liquid propellent rocket, the propellants are stored in tanks and fed into the burning chamber either under the driving force of a high-pressure gas or by means of high-speed pumps. Ordinarily, liquid propellent rockets are "bipropellent" vehicles; that is, they use two different liquids, one (such as refined kerosene or liquid hydrogen) as fuel; the other (such as nitric acid or liquid



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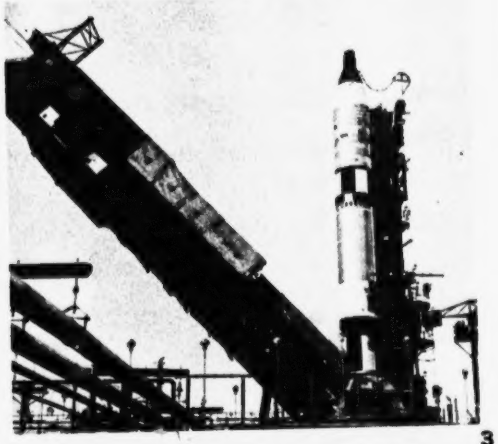

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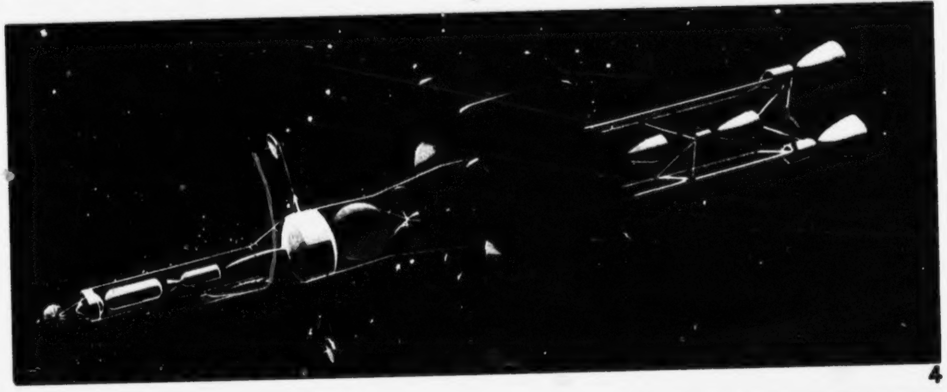

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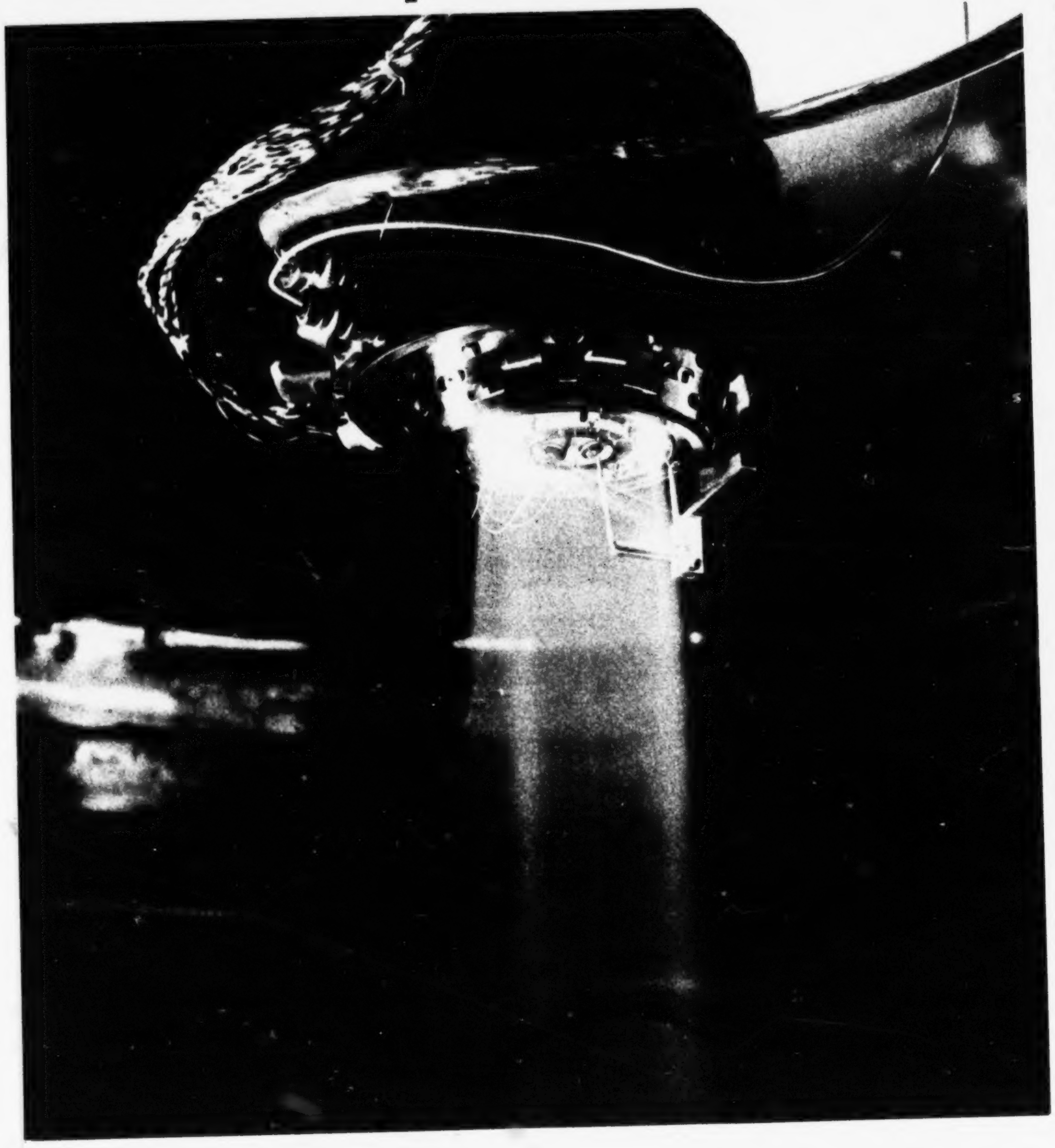

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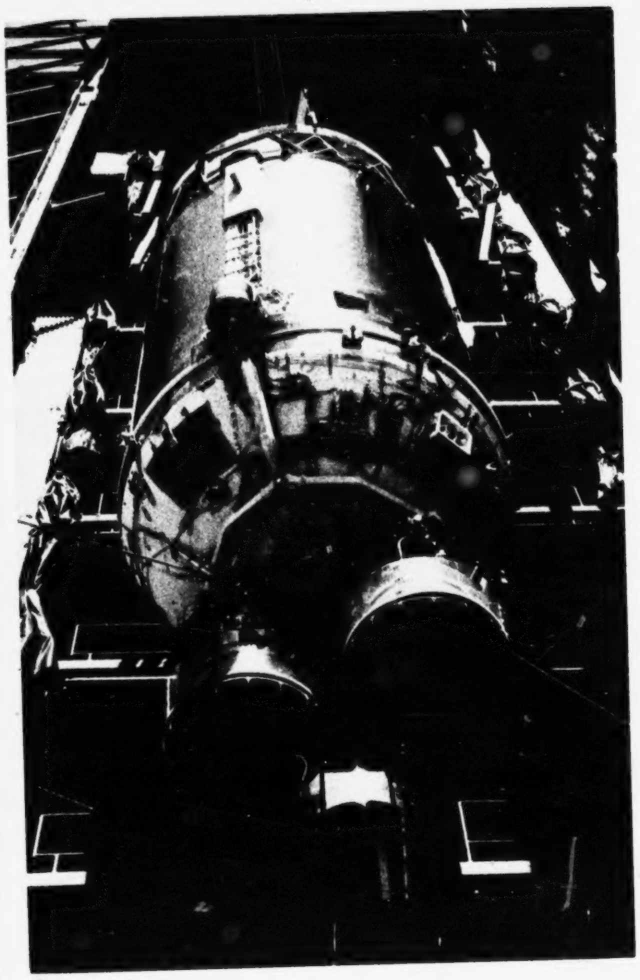

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oxygen) as the oxidizer. There are, however, monopropellent liquid rockets, in which a single propellant is decomposed to produce the jet.

A solid propellent rocket is one in which the fuel and oxidizer are mixed in solid form, usually as a powdery or rubbery mixture known as the "grain" or "charge." The grain is packed in the rocket casing, which serves as both storage and burning chambers.

In general, liquid-propellent rockets are considerably more complex than solid-propellent rockets. However, it is possible to control the combustion in liquid propellent rockets with the simple closing or opening of a valve. Burning of a solid mass as in the solid rocket cannot be controlled in such a way.

Research programs are constantly under way to improve the performance of existing rocket vehicle systems. Among the techniques employed are finding ways to increase propellant tank capacities and to reduce excess equipment, adding strap-on rockets, and developing new fuel combinations.

Engineering improvements have already significantly increased the capabilities of the all-solid-fuel Scout and the liquid-fuel Atlas and Delta launch vehicles, for example. Strap-on solid rockets have added substantially to the lift-off thrust of the Delta and Thor-Agena launch vehicles.

Experimenters are working to harness the energy of the more volatile and corrosive liquid fluorine. It is estimated that using fluorine in conjunction with either oxygen or hydrogen can increase markedly the capacities of today's liquid rockets.

Another type of liquid fuel technology employs hypergolic fuels. Hypergolic fuels ignite on contact, thus eliminating the needs for igniters and related equipment. Use of hypergolic fuels reduces such temperature requirements as keeping liquid oxygen lower than 297.4 degrees below zero Fahrenheit and liquid hydrogen lower than 423.04 degrees below zero Fahrenheit. Liquid oxygen and liquid hydrogen vaporize above these respective temperatures.

Among hypergolic fuels in use are unsymmetrical dimethyl hydrazine (abbreviated UDMH) and monomethyl hydrazine. When the oxidizer, nitrogen tetroxide (N204), contacts either fuel, the two ignite. Hypergolic combinations are employed in the Titan II and in the second stages of Delta, Thor-Agena, and Atlas-Agena.

In addition to improving the Scout, NASA is conducting other studies and tests to advance solid-propellent rocket technology and to determine whether large solid-fuel motors can be useful for future space missions.

Ground firings of 260-inch diameter solid-fuel motors were conducted September 25, 1965, and February 23, 1966. During the tests, the 60-foot long motors developed about 3.5 million pounds of thrust. The Scout, largest American solid-propellent vehicle in operation, generates a lift-off thrust of 87,000 pounds.

FUTURE PROPULSION The performance available to chemical rockets is clearly limited by the roughly 400 seconds specific impulse that constitutes the theoretical maximum and by the mass ratios obtainable with best engineering practice. In order to obtain vehicles with performance great enough to carry out long-term and extreme distance space missions, it will become necessary to develop new propulsion systems with performance capabilities superior to those of the chemical rocket. Looking toward exploration of the solar system, research is being conducted on such propulsion systems as the following:

NUCLEAR FISSION / This is a powerplant which uses the enormous heat of nuclear fission (atom splitting) in a nuclear reactor to heat a "working fluid," which might be hydrogen, helium, or ammonia in liquid form. This heated fluid is then channeled through a nozzle in the conventional rocket fashion. It is estimated that specific impulses ranging from 800 to 1000 seconds can be obtained with this system.

NASA — AEC NUCLEAR ROCKET ENGINE PROGRAM (ROVER) / Rover is a joint program of NASA and the Atomic Energy Commission to develop a nuclear rocket engine. The feasibility of a nuclear rocket with a 1000-megawatt (one-billion watt) nuclear reactor was demonstrated in Project Kiwi. Kiwi reactors, like the flightless New Zealand bird for which they were named, were never intended for flight. The Phoebus project, which has followed Kiwi, is testing reactors ranging from sizes used in Kiwi to those providing as much as 5000 megawatts of power.

Ground tests and evaluations are being conducted on the ground with nuclear rocket engine systems based on Kiwi and Phoebus technologies. These tests and evaluations are part of the NERVA (*N*uclear *E*ngine for *R*ocket *V*ehicle *A*pplication) project. The complete NERVA system (including the reactor and other components) passed its first ground test on February 3, 1966.

ELECTRIC PROPULSION / The first expected practical use of electric propulsion is in satellite station-keeping and attitude control. (Station keeping involves slight changes in a satellite's orbit. Attitude control refers to the turning or rolling of a satellite to a desired orientation.) Eventually, electric rockets may be used for station keeping and attitude control of large manned space stations and for mid-course maneuvers of unmanned interplanetary spacecraft. Studies are being conducted on the following kinds of electric propulsion:

ION ENGINES / The ion rocket engine produces thrust by electrically accelerating charged particles (atomic particles such as protons and electrons). One of the propellants used for ion engines is a rare element called cesium. Cesium readily ionizes when heated; that is, each atom of cesium gives up an electron. Removal of the electron, which bears a negative electric charge, causes the remaining cesium atom (called an ion) to be positively charged.

Ion rockets produce very little thrust. However, because their rate of fuel consumption is low, they can sustain this thrust over long periods. Among other desirable features of ion rockets are that they are relatively light in weight and can easily be stopped and restarted.

ARC JET ENGINE / This engine is similar to a chemical rocket, except that it uses fuel and electrically created heat instead of fuel and an oxidizer. As an example, a propellent gas such as liquid hydrogen is passed through a high temperature electric arc where it is electrically heated to several thousand degrees and expelled through the rocket nozzle. The exhaust velocity, thrust, and specific impulse theoretically obtainable are far in excess of any known chemical or nuclear fission system.

RESISTOJET ENGINE / Like the arc jet engine, this system accelerates a propellant by electrically heating it to high temperatures. In the resistojet engine, however, heat is generated by passing an electric current through a special wire or tube which presents high resistance to the current's passage. A phenomenon called resistance heating results. Resistance heating is the principle on which electric toasters, waffle makers, irons, and other electrical heating appliances operate.

PLASMA ACCELERATOR / The plasma accelerator employs electric heat on a propellant gas whose atoms can be easily ionized. As a result, a stream of ions called a plasma is created. A magnetic field accelerates the gas particles to very high velocities before ejecting them through the rocket nozzle. Specific impulses that may be attained are many times those of chemical, nuclear, arc jet, or resistojet engines.

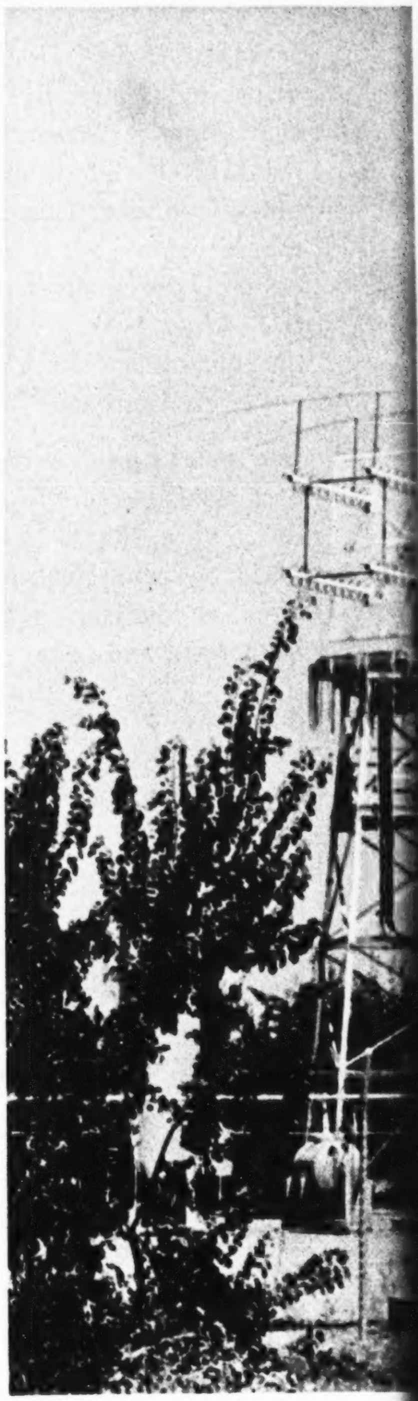
SOLAR ELECTRIC ENGINE / Space literature frequently refers to a solar-electric engine. This propulsion unit combines an electric engine, such as an ion rocket, with a system for converting sunlight to electricity, such as a large array of solar cells (see Chapter XIII, Electrical Power Generation, Guidance, and Communications). An advantage of the solar electric engine is that it could operate throughout an unmanned flight; for example, from earth to Mars. This would enable controllers on earth to match the speed of the Mars spacecraft precisely with that required for the mission. As a result, the craft's velocity as it neared Mars would be lower than that of a chemically propelled (solid- or liquid-propellent) craft. Consequently, less retropropulsion (slowing down or braking power) would be required to place the spacecraft into an orbit around Mars or soft-land it on the planet. (With chemical propulsion, a few in-flight blasts can be employed to set the spacecraft on course. The velocity of the chemically propelled spacecraft as it approaches its planetary destination would tend to be much higher than that of the electrically propelled craft whose in-flight velocity could be frequently adjusted.)

PHOTON ROCKET / Light exerts pressure, hence a more remote possibility is the photon rocket, wherein photons, or light particles, would provide the thrust. Such rockets would be capable of extremely high specific impulses, but would require radiation of tremendously intense beams of light. For the time being such rockets must be considered only speculative.

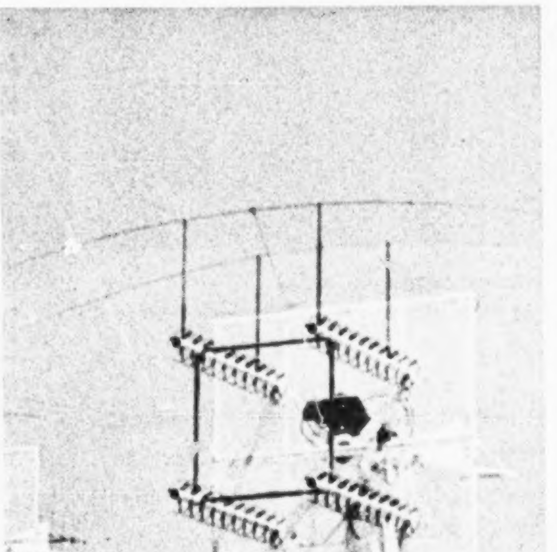
Electrical Power Generation, Guidance & Communications

XIII

POWER GENERATION Electrical power is needed on nearly all spacecraft. Spacecraft designed for relatively short-term experiments are equipped with chemical storage batteries that can supply adequate power for the period. However, advances in space increasingly call for light-weight compact equipment that can generate electrical power at given levels for long periods. Among devices in use or on which studies are in progress are the following: *SOLAR CELLS* / For the most part, spacecraft of the United States have been powered by solar cells in combination with rechargeable storage batteries. The solar cells are photoelectric devices that convert sunlight to electricity. Studies are in progress to increase the generating capabilities of the solar cells and to make them lighter in weight and more resistant to damage from radiation. *FUEL CELLS* / Fuel cells convert gases such as liquid hydrogen and liquid oxygen to electricity. They have been used on several Gemini spacecraft. *SNAP* / SNAP stands for *S*ystems for *N*uclear *A*uxiliary *P*ower. It involves a series of nuclear-power projects by NASA, AEC, and the Department of Defense. ¶ Systems being evaluated would provide a broad range of power from 2½ watts to 1000 kilowatts. The systems function by converting heat from nuclear reactions to electricity. The low-power units, generally designated by odd numbers such as SNAP-19, use radioisotopes. The systems that meet larger electric power requirements, generally designated by even numbers such as SNAP-8, use nuclear reactors to create heat.



GUIDANCE Space exploration makes use of several fundamental forms of guidance. These are inertial or programmed; semi-inertial, that is, basically inertial but having some outside guidance added; radio or command; celestial or star tracking; and infrared. ¶ Because the inertial system is completely independent of information outside the spacecraft, it is presently most relied upon for space travel. ¶ Inertial guidance is the method of determining the position and velocity without referring in any way to the world around the vehicle. This system does not depend upon receiving radio signals, a measurement or a count of any kind. Its fundamental devices are accelerometers, memory devices, and gyroscopes. It depends upon measuring the acceleration of the vehicle by measuring the force exerted on a body within the vehicle due to this acceleration. This is the same force that pushes us back into our seats when an automobile starts moving or increases speed. ¶ Theoretically, inertial guidance can take a vehicle to any point any place in the universe. ¶ Semi-inertial guidance has basically the same equipment as inertial guidance



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and uses the same technique, but it also contains equipment to receive other information. This may come by command from the earth or aboard the craft or it can also be in a form of star tracking. ¶ One of the basic requirements of the inertial system is that the exact location of launch be known. By adding a star-tracking device which can obtain a fix once it is out of the atmosphere, this necessity is eliminated. The star tracker supplies the information by taking a fix on a predetermined star and then computing the position of the spacecraft relative to earth. ¶ The use of command or radio guidance, of course, requires that the space vehicle contain a receiver capable of accepting directions from ground stations and of executing these commands through its control system. ¶ Celestial bodies emit infrared rays. These rays can be detected by a photoelectric device which translates the infrared variations into voltage changes. These changes provide guidance information — hence infrared guidance.

COMMUNICATIONS Telemetry refers primarily to making measurements at a remote location and transmitting these measurements for reproduction at another location. The information obtained may be in a form suitable for display, for recording, or for use in computing machines. ¶ In unmanned space exploration, telemetry has helped perfect the design of vehicles by monitoring their performance during flight. ¶ In manned flight, telemetered signals supplement the messages sent by the astronaut and permit the use of complex computing equipment on the ground which would be much too heavy to carry in the space vehicle. ¶ The power required to send telemetered signals from satellites and space probes is infinitely small-

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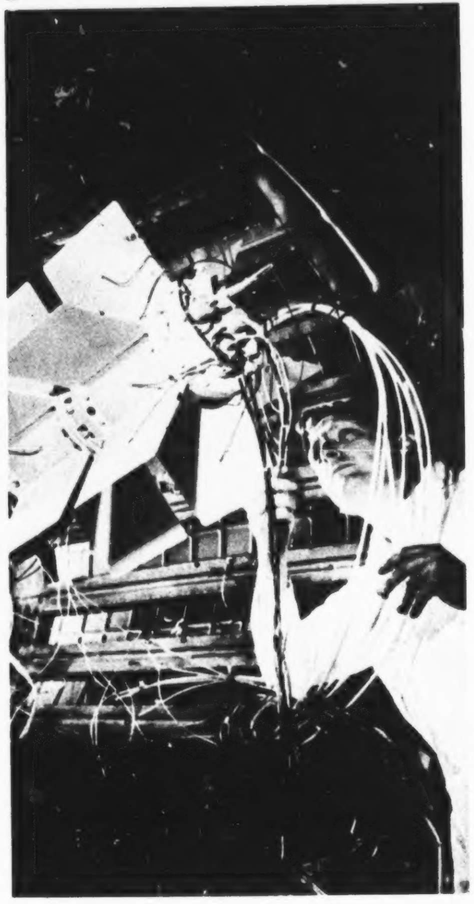
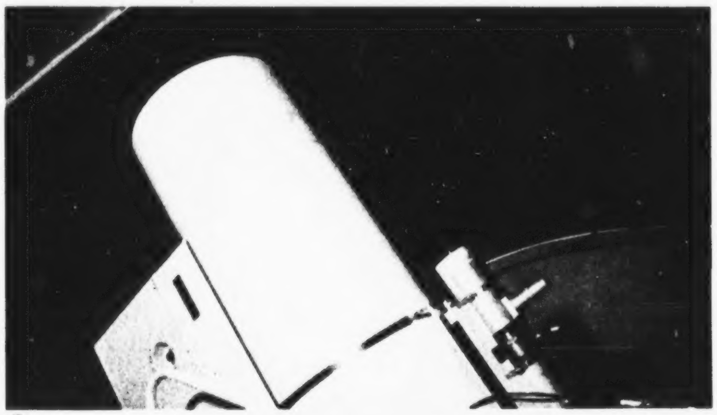


1. *Tracking antenna of Manned Space Flight Network at Kano, Nigeria.*

2. *Two SNAP-19 nuclear electric generators are wired to advanced version of Nimbus weather satellite. In this case, they supplement the power produced by solar cells.*



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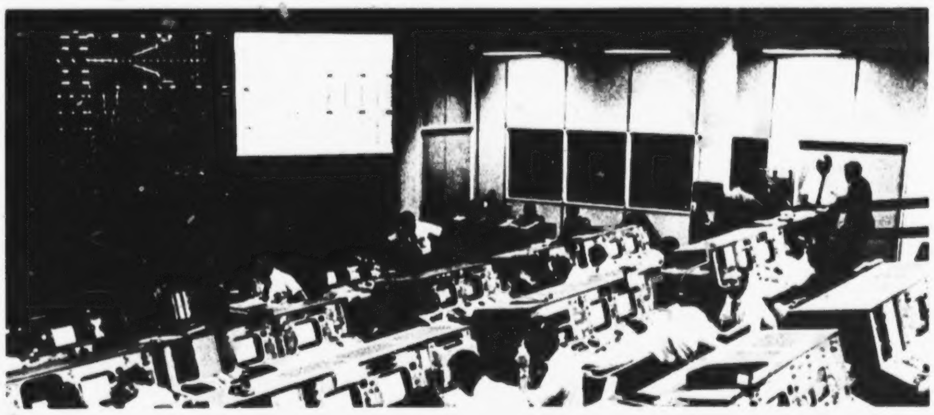

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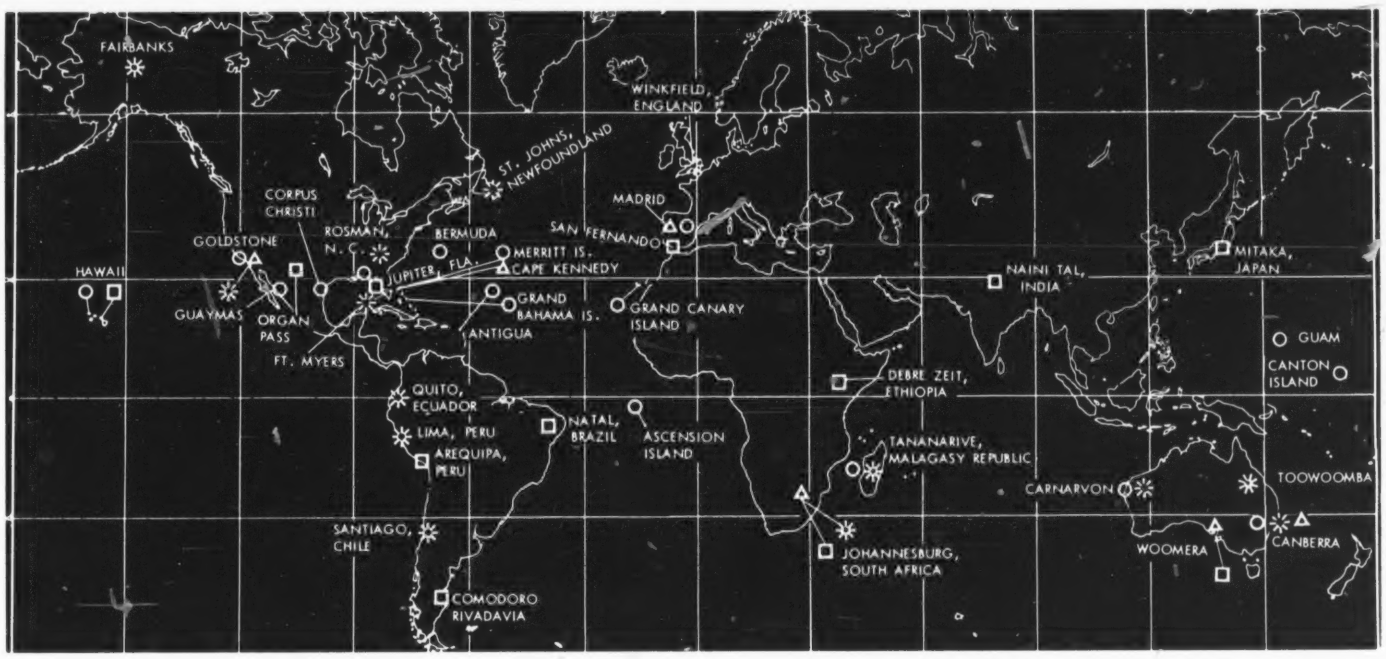
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ROSMAN, N. C.
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GOLDSTONE
MERRITT IS.
CAPE KENNEDY
HAWAII
JUPITER, FLA.
NAINI TAL, INDIA
MITAKA, JAPAN
GRAND BAHAMA IS.
GRAND CANARY ISLAND
GUAYMAS
ORGAN PASS
ANTIGUA
GUAM
FT. MYERS
DEBRE ZEIT, ETHIOPIA
CANTON ISLAND
QUITO, ECUADOR
NATAL, BRAZIL
ASCENSION ISLAND
LIMA, PERU
AREQUIPA, PERU
TANANARIVE, MALAGASY REPUBLIC
CARNARVON
TOOWOOMBA
SANTIAGO, CHILE
JOHANNESBURG, SOUTH AFRICA
WOOMERA
CANBERRA
COMODORO RIVADAVIA

3

○ *Manned Space Flight Network*
* *Satellite Tracking and Data Acquisition Network*
△ *Deep Space Instrumentation Facilities*
☐ *Optical Tracking Network*

er than that required for commercial radio and television stations. Data were received from Mariner IV's 10-watt transmitter when the spacecraft was more than 191 million miles from earth. Radio contact, but no data acquisition, was achieved with Mariner IV when it was 216 million miles away.

One reason such ranges can be achieved with so little power is that ground radio systems used to communicate with spacecraft have extremely sensitive receivers. For example, the 85-foot-diameter antennas that communicated with Mariner are about 20,000 times more sensitive than the average rooftop television antenna.

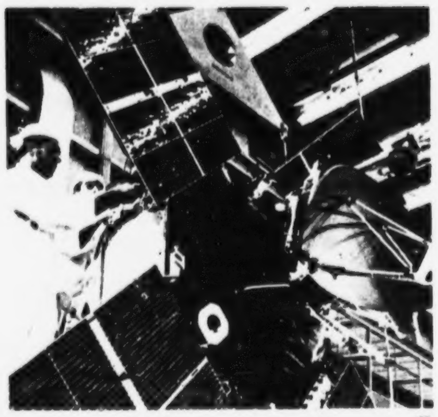
Radio telescope studies have shown that with sufficiently powerful transmitters and sensitive receivers, we can communicate over interstellar distances.

However, there are problems. One is that beyond the solar system, so many stars and other celestial entities emit radio waves that they pose a threat to clear communication with spacecraft. Another limiting factor is distance itself. Radio waves travel at about the speed of light which is approximately 186,000 miles per second. It takes only about 5 minutes for a message sent from earth to reach Venus, when Venus is closest to earth. However, a message from earth to a spacecraft in the vicinity of Pluto would take more than 5 hours to reach its destination.

The radio signals emitted by spacecraft permit ground stations to communicate with, acquire data from, and track them with a high degree of accuracy.

Experiments are being conducted in using laser beams for communication. Laser, which stands for *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation, is a light beam of a single frequency. *Ordinary light is a mixture of frequencies.* Because laser beam frequencies are much higher than radio frequencies, they can carry far more information than radio.

TRACKING AND DATA ACQUISITION FACILITIES NASA operates three major ground track-



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1. *Laser device in action. Note thin laser beam.*
2. *Mission Operations Control Room in Mission Control Center, Houston, Texas, moments before Gemini spacecraft launch.*
3. *Tracking facilities of NASA and the Smithsonian Astrophysical Observatory.*
4. *Technician at Goldstone Deep Space Instrumentation Facility observes 85-foot diameter antenna as he operates equipment.*
5. *Baker-Nunn satellite tracking camera of the Smithsonian Astrophysical Observatory.*
6. *A fuel cell unit tested in Gemini flights.*
7. *Close-up of solar cells on windmill-like panels of Mariner IV, the spacecraft that sent the surprising pictures from Mars.*

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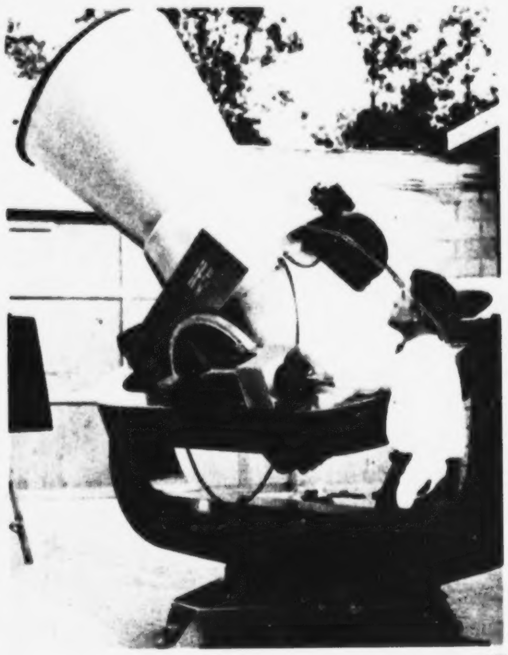

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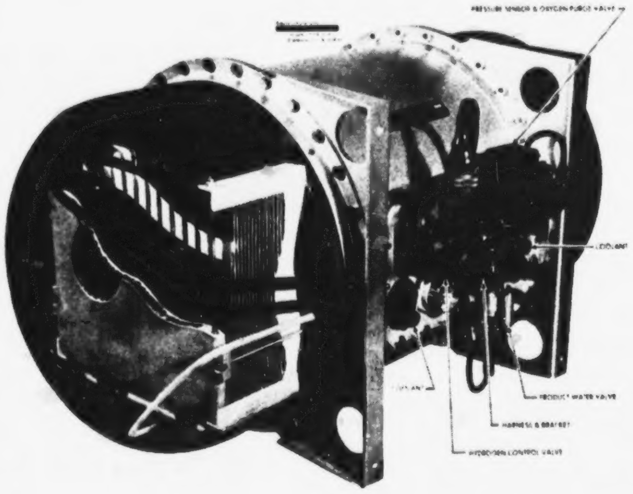

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ing and data acquisition networks. One is the Space Tracking and Data Acquisition Network (STADAN). It is an outgrowth of the Minitrack Network established for experiments of the International Geophysical Year of 1957 and 1958. Its fixed stations employ radio and optical equipment to track and gather data from unmanned satellites such as the Explorers, Orbiting Geophysical Observatory and others.

Another major network is the group of stations known as Deep Space Instrumentation Facilities (DSIF). These are equipped with huge antennas (no less than 85 feet in diameter) to pick up the faint signals from spacecraft that may be millions of miles from earth. DSIF picked up the pictures and information that the Mariners and Rangers sent about Venus, Mars, and the moon.

The Manned Space Flight Network (MSFN) is used primarily for support of manned missions into space, particularly Projects Mercury, Gemini, and Apollo. The network is continuously improved to meet the requirements of increasingly more complex manned missions. *Equipment is also being installed at some DSIF locations for Project Apollo, in which American astronauts will first explore the moon.*

Another global group of stations that track satellites is the network of the Smithsonian Astrophysical Observatory (SAO). The principal equipment at each station is a huge Baker-Nunn high-precision telescopic camera.

STADAN funnels all of its data to the Communications and Computing Center at NASA's Goddard Space Flight Center, Greenbelt, Maryland. The command center for manned flights is the Mission Control Center which is set up at NASA's Manned Spacecraft Center, Houston, Texas. The DSIF funnel their information to the Space Flight Operations Facility at NASA's Jet Propulsion Laboratory, Pasadena, California.

A map shows the locations of the fixed STADAN, DSIF, MSFN, and SAO stations. Not shown are the ship stations of the MSFN whose positions vary with the particular manned space flight.

Other Research Activities

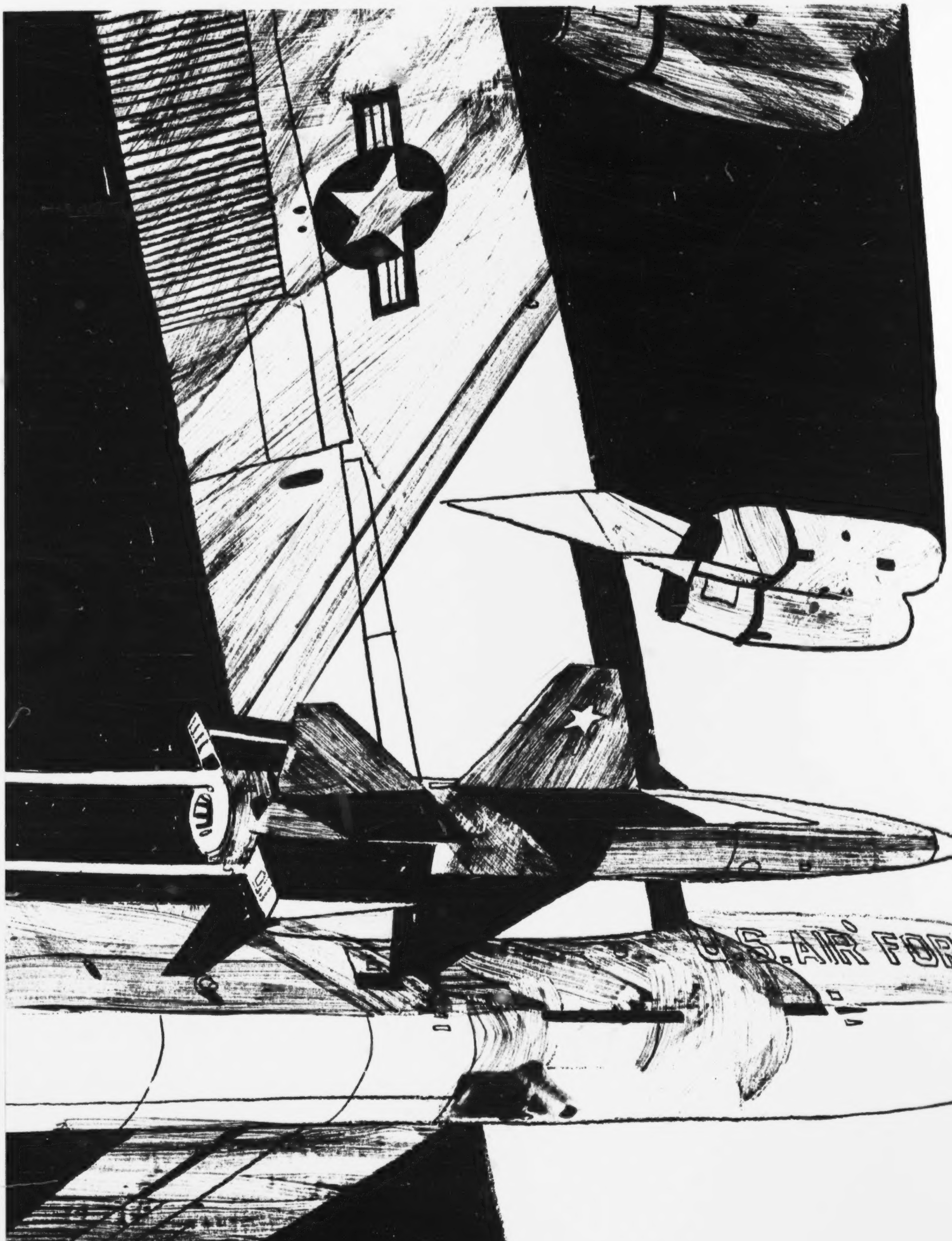
XIV

Some of the fundamental research in support of space programs has been presented earlier in this book. Among the subjects that have been covered are rocket propulsion, power generation, biological aspects of space flight, X-15 missions, and meteoroid satellite studies. A few additional areas of study are discussed below.

ENTRY HEATING Ground studies and flight tests are increasing knowledge about what happens to spacecraft that enter the atmosphere at speeds of approximately 25,000 miles per hour. This is the velocity that the Apollo spacecraft will have when it reaches earth's vicinity on returning from the moon. In Project Fire, instrumented packages, launched by Atlas boosters, were accelerated to a speed of about 25,000 miles per hour as they headed back toward earth. Information from the project supplemented analytical and wind tunnel research on heating during atmosphere entry at such a speed.

RADIO BLACK-OUT DURING ATMOSPHERE ENTRY Studies in ground laboratories and in space are in progress to solve the problem of the radio black-out which occurs as a vehicle enters the atmosphere after a space flight. The black-out is caused by formation of ionized gas around the vehicle. This ionized gas, which is electrically charged, tends to absorb radio waves. Flight experiments connected with this study are called Project RAM (for *R*adio *A*ttention *M*easurement).

RAMJET ENGINE NASA is looking into the potentials of ramjet engines for a variety of aeronautic and space uses. Such engines differ from conventional jet engines, which burn fuel with air that is mechanically compressed by turbine-like wheels. The ramjet engine literally compresses air by ramming through it at high speeds. ¶ The ramjet engine is believed to be economically superior to others at hypersonic speeds (speeds of Mach 5, or five times the speed of sound, or greater). It is being considered for possible use in future hypersonic transport aircraft, launch vehicle stages, and maneuverable ferry vehicles returning from journeys between earth and orbiting space stations.


U.S. AIR FORCE

FUEL SLOSHING This is one of many seemingly prosaic problems in launch vehicle development. Anyone carrying a container of liquid for any distance knows what sloshing is. When tons of liquid propellant slosh around in the fuel tank of a rocket, they can burst its walls. Baffles (circular rings) are used to damp such sloshing. Continued studies are aimed at reducing the weight of the baffles.

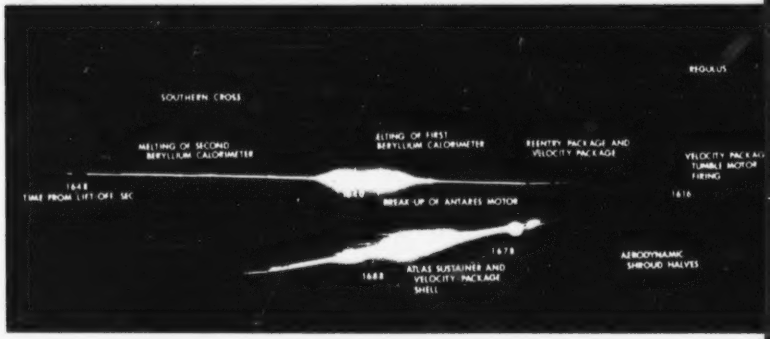
REDUCING SUPPORT REQUIREMENTS OF MOON BASE If a lunar base can be partially supported by materials already on the moon, the requirements for establishing and maintaining the base would be substantially reduced. Studies are being made on the possible production, processing, and use of materials on the moon for the construction, supply, and operation of manned lunar bases. Among other objectives is to learn whether lunar materials can be used to provide shelter, water, and fuel. Scientific findings from NASA's unmanned lunar programs, especially Surveyor, will be used in their studies.

MATERIALS AND STRUCTURES A vacuum such as in space can cause unearthly changes in objects. Rubber becomes hard and brittle and oil vaporizes. Moreover, radiation modifies materials and can damage equipment. A major consideration in designing and constructing spacecraft is development of materials, structures, and equipment that are resistant to radiation and can function in a vacuum.

Still another problem is temperature control. The side of a body in space that faces the sun can become very hot while the other side becomes extremely cold. To date, temperature control of spacecraft has been accomplished principally by use of passive temperature control systems such as metals, ceramics, and plastics that are good heat conductors, by louvers that permit built-up heat to escape, and by use of dark and light colors for heat absorption and reflection.

For space missions to Mercury or to Jupiter and the outer planets, active refrigeration and heating systems powered by a nuclear electric generating device such as SNAP are required. Development of such systems is under study.

ELECTRONICS It has been estimated that about 70 percent of spacecraft costs involve electronic systems through which the vehicles are guided and function and through which contact with earth is maintained. As an example, the Mercury


REGULUS
SOUTHERN CROSS
MELTING OF SECOND BERYLLIUM CALORIMETER
ELTING OF FIRST BERYLLIUM CALORIMETER
REENTRY PACKAGE AND VELOCITY PACKAGE
VELOCITY PACKAG TUMBLE MOTOR FIRING
1648
TIME FROM LIFT-OFF, SEC
BREAK-UP OF ANTARES MOTOR
1616
1678
AERODYNAMIC SHROUD HALVES
1688
ATLAS SUSTAINER AND VELOCITY PACKAGE SHELL

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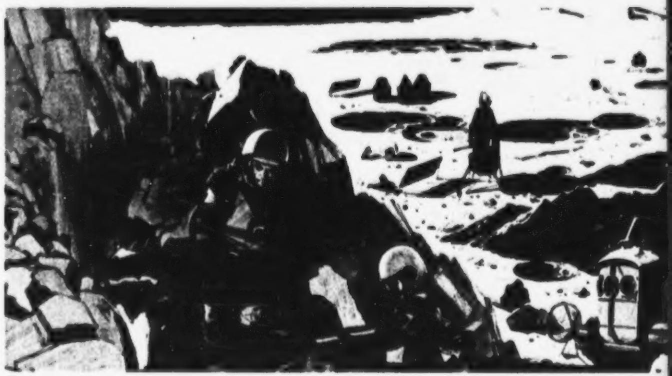

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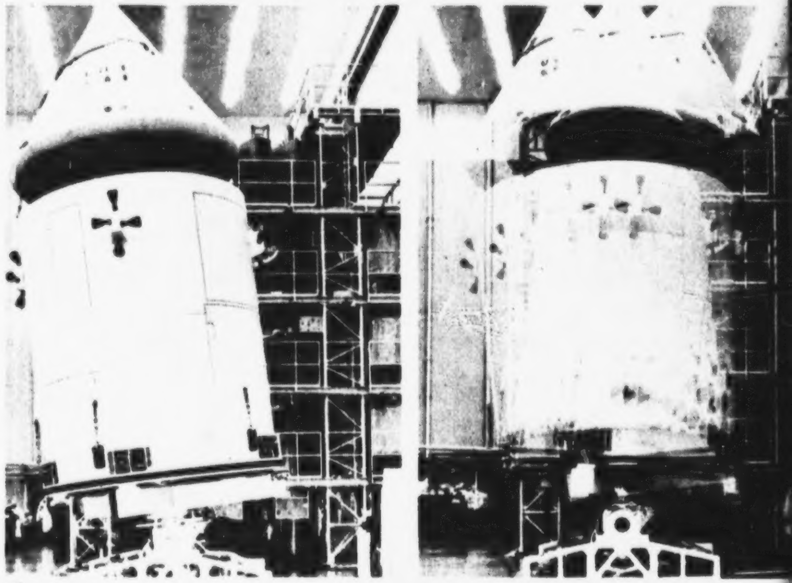

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spacecraft—a relatively simple vehicle compared to those for advanced missions—contained 7 miles of electrical wiring, hundreds of switches, instruments, radios, lights, and other electronic apparatus. Advanced research into the technology of electronics and related fields is important to the success of space exploration. One of the major areas in which space engineers are currently engaged is microelectronics—reduction in size and increase in efficiency and reliability of electronic circuits and other devices. As an example, microelectronics has reduced the size of all the circuits in a radio to fit a case smaller than a sugar cube.

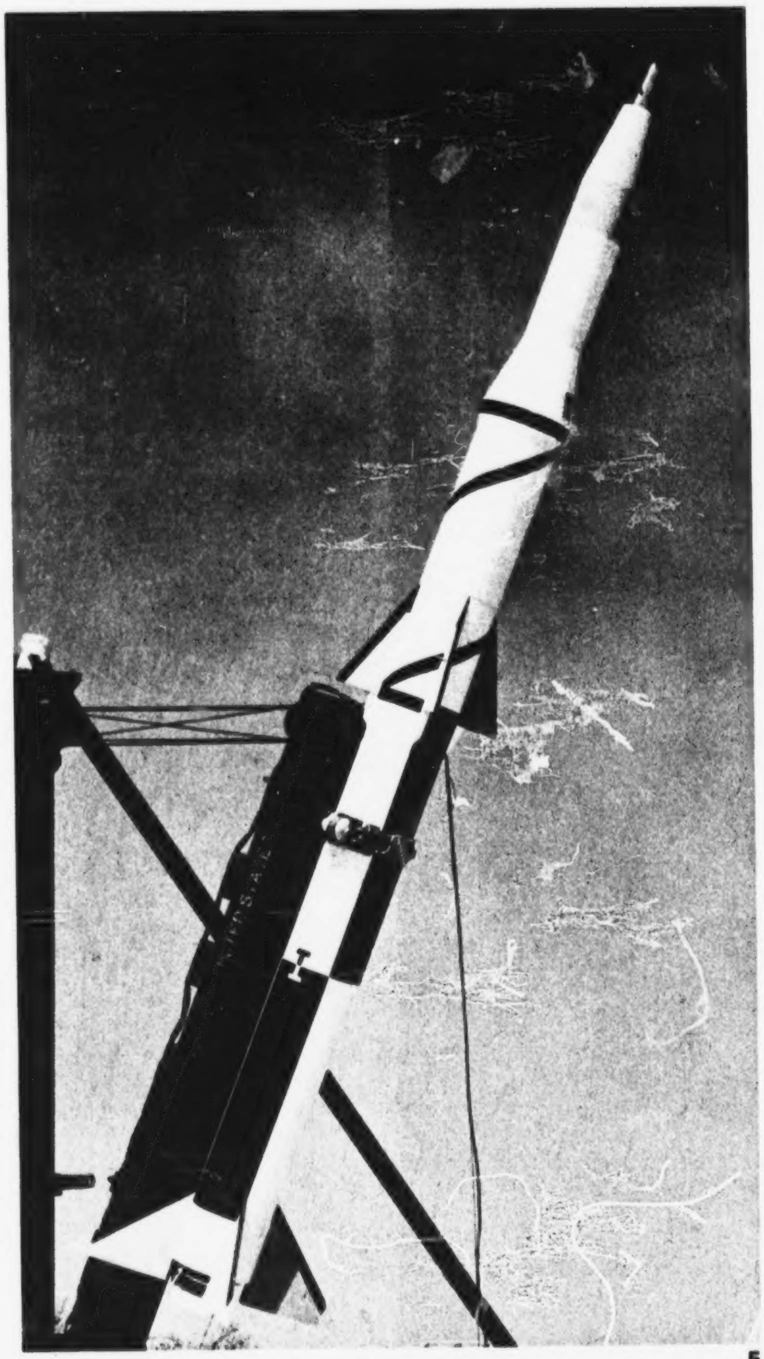
Electronics research covers a broad range of space activities. It is designed to find new and better ways for communications, tracking, guidance, control, stabilization, and data gathering and processing as applied to space missions. Such advances are expected to contribute to progress in everyday living.

SIMULATORS To simulate is to assume the appearance of, without reality. This is exactly what simulators on the ground are supposed to do. Special chambers seek to duplicate the temperatures, vacuum, and radiation of space, enabling engineers to check out their spacecraft before launching them. Other machines perform such functions as shaking the spacecraft to determine whether it can withstand the vibrations of launch.

Several manned space flight simulators are in use. A Space Vehicle Rendezvous Docking Simulator is designed to simulate the last two hundred feet of maneuvers in which craft are joined in either earth or lunar orbit. Facilities to give practice in landing a vehicle on the airless moon, using only rocket power, have been established. Other equipment enables the astronauts to walk and work as they would on the moon.

WIND STUDIES Among the numerous forces acting on a launch vehicle are winds. These are a problem not only on the ground but also after launching. Winds are a major problem because launch vehicles are structurally thin-skinned and flexible rather than rigid.

Sounding rocket studies reveal regions of intense turbulence and strong wind shears (layers of winds at different altitudes blowing in different directions) at heights in the vicinity of the jet stream (about 30 feet). The wind may cause the launch vehicle to oscillate and go off course.



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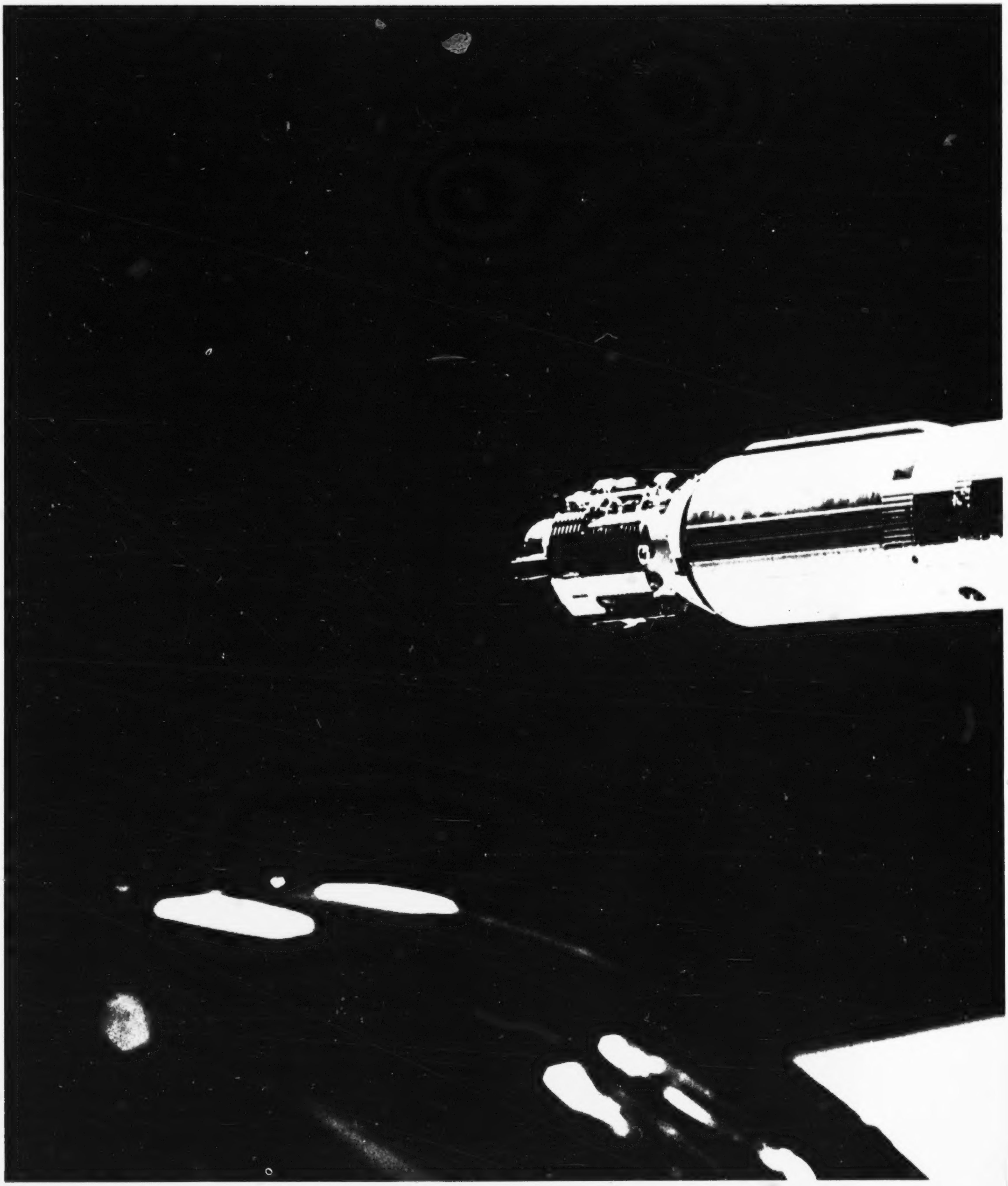
1. *Project Fire experiment produces spectacular display in night sky. The composite photograph was taken by a camera on Ascension Island in the South Atlantic Ocean. The long horizontal streak at the top is the trail of the Fire re-entry package and the Antares rocket. Antares accelerated Fire to the required velocity after launch by Atlas. Other streaks are made by the Atlas launch vehicle (large lower streak), Fire's protective coverings during launch, the "tumble" rockets that separated Fire and Antares, and the star background.*
2. *Lunar exploration (artist's conception).*
3. *Apollo spacecraft rocks and rolls in shake test.*
4. *Wind profile is made by rocket-borne smoke generator.*
5. *RAM flight experiment is set up for launch.*



The Agena Target Docking Vehicle seen from the Gemini VIII spacecraft.